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ABSTRACT

The focus of this seminar was on how teachers learn to teach academic subjects to diverse learners and what they need to know to be effective instructors. The following papers were presented: (1) "Policy Implications of Research on Science Teaching and Teachers' Knowledge" (Charles W. Anderson); (2) "What Teachers Need to Know to Teach Science Effectively" (Anton E. Lawson); (3) "What Teachers Need to Know to Teach Science Effectively" (Arnold A. Strassenburg); (4) "Teaching Mathematics for Understanding: What Do Teachers Need to Know about Subject Matter?" (Deborah Loewenberg Ball); (5) "Preparing Elementary Teachers to Teach Mathematics" (E. Ray Phillips and A. Edward Uprichard); (6) "What Do Math Teachers Need to Be?" (Herbert Clemens); (7) "Parades of Facts, Stories of the Past: What Do Novice History Teachers Need to Know?" (Suzanne M. Wilson); (8) "Social Science Knowledge and Citizenship Education" (James A. Banks); (9) "Knowledge for Teaching History" (Catherine Cornbleth); (10) "Musts for Writing Teachers--Report from the Classroom" (Tom Romano); (11) "The Knowledge Necessary to Teach Writing Effectively" (George Hillocks, Jr.); and (12) Teaching/Writing in a Community of Inquirers" (John T. Gage). (JD)

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Conference Series 89-1

Competing Visions of Teacher Knowledge: Proceedings From an NCRTE Seminar for Education Policymakers February 24-26, 1989

Volume 1: Academic Subjects

National Center for Research on Teacher Education

NCRTE

National Center for Research on Teacher Education

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Conference Series 89-1

COMPETING VISIONS OF TEACHER KNOWLEDGE: PROCEEDINGS FROM AN NCRTE SEMINAR FOR EDUCATION POLICYMAKERS

February 24-26, 1989

Volume 1: Academic Subjects

National Center for Research on Teacher Education

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National Center for Research on Teacher Education

The National Center for Research on Teacher Education (NCRTE) was founded at Michigan State University in 1985 by the Office of Educational Research and Improvement, U.S. Department of Education.

The NCRTE is committed to improving teacher education through research on its purposes, its character and quality, and its role in teacher learning. NCRTE defines teacher education broadly and includes in its portfolio such diverse approaches as preservice, inservice, and induction programs and alternate routes to teaching.

To further its mission, the NCRTE publishes research reports, issue papers, technical series, conference proceedings, and a newsletter on contemporary issues in teacher education. For more information about the NCRTE or to be placed on its mailing list, please write to the Editor, National Center for Research on Teacher Education, 116 Erickson Hall, Michigan State University, East Lansing, Michigan 48824-1034.

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Many papers published by the NCRTE are based on the Teacher Education and Learning to Teach Study, a single multisite longitudinal study. The researchers who have contributed to this study are listed below:

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Preface

Mary M. Kennedy

A popular pastime today is to develop lists of what teachers need to know. Such lists can have a settling effect; by enumerating all the elements of good teaching, we have cleared up at least one of life's many confusions. But in fact, these lists do not solve very much, for each entry on each list is complicated in itself. Every researcher who has tried to define teacher knowledge, every policymaker who has tried to measure it, and every teacher educator who has tried to enhance it, knows the myriad problems and perplexities that are bubbling underneath the surface of each entry on these lists.

Like many others, The National Center for Research on Teacher Education (NCRTE) has also been struggling to understand the nuances of these entries. The Center is trying to learn how teachers learn to teach academic subjects to diverse learners. In light of this mission, the Center is especially interested in two particular list entries: "academic subjects" and "diverse learners." These two entries make nearly everyone's list, but like other entries, their full meaning has yet to be determined.

On February 24-25, 1989, in Washington, D.C., the NCRTE sponsored a conference for educational policymakers to examine these two entries. For academic subjects (Volume 1), we focused on science, mathematics, history and writing; for student diversity (Volume 2), we focused on student cognition and on student cultural backgrounds. Rather than seeking out one authority in each of these domains, we sought three. And we sought people whom we expected to view their assigned topics from diverse perspectives. Our goal was to delve deeply into each topic, to understand each topic in far more depth than is permissible at the level of list entries. So, for instance, we viewed student cognition from the point of view of Vygotskyian theory, conceptual change theory, and behavior change. And we viewed writing from the viewpoint of a teacher, a researcher, and a disciplinarian.

The papers in this volume derive from that seminar. Among other things, we discovered that the conceptual struggles within these fields were not as diverse as one might expect. Instead, there are a small number of tensions that seem to be repeated in many different fields. Both science educators and writing educators, for instance, are torn between defining their subject as a body of content and defining it as a way of thinking and behaving. Both mathematicians and historians find it difficult to convince novices that their knowledge is tenuous, not fixed. People in all four of these fields experience a tension between the way the subject is perceived by its most advanced thinkers and the way it is perceived by naive students.

Among other things, we all became aware of the struggles and tensions within each field, of the difficulties of defining ideas, and of the many faces each of these fields really has. Seeing each field portrayed from a variety of perspectives was interesting and intellectually stimulating in itself. Seeing analogous dilemmas emerge across such diverse fields made the conference particularly stimulating. In fact, it was especially so for the speakers who represented the various disciplines, for many of them had never had the opportunity to examine another field very closely. The opportunity to do so enabled them to better understanding conflicts within their own fields. Our hope is that, by making these proceedings available to others, we can provide a similar experience for a broader group.

Acknowledgments

I would like to acknowledge the organizational talents of Joan Eadie who organized the conference in Washington, D.C., the thoroughness of Sandra Gross for tracking and editing the proceedings papers, and the perseverance and dedication of Anna G. Edridge and Kris Langham for preparing the individual papers for publication in this volume.

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POLICY IMPLICATIONS OF RESEARCH ON SCIENCE TEACHING AND TEACHERS' KNOWLEDGE

Charles W. Anderson[1]

The central fact with which any discussion of science teachers' knowledge must contend is the failure of our present system of science education. This failure is not of recent origin, nor is it absolute, but recent evidence from a variety of sources has documented the nature and extent of our failure more thoroughly than ever before. For example, when Yager and Yager (1985) tested students' ability to select correct definitions for terms from the biological and physical sciences, they found evidence that seventh graders did better than third graders, but there was no improvement at all between seventh and eleventh grades, despite the fact that most students take several science courses in between. In the most recent studies of science achievement by the International Association for the Evaluation of Educational Achievement (1988), American high school seniors were dead last among 13 ranked countries in their assessed biological knowledge; they ranked eleventh in chemistry, ninth in physics. Jon Miller (1988) found that only 48 percent of American adults knew both that (a) the earth revolves around the sun, rather than the other way around, and (b) that it takes a year to do so, rather than a month or a day.

This pattern of failure is not a surprise to anyone who has spent much time observing science classrooms. A lot of science teaching is dull and meaningless stuff--an amalgam of boring lectures, cookbook "experiments," and worksheets or written work. Textbooks are for the most part poorly written and overloaded with technical vocabulary. Even what we normally call "good" science teaching generally fails to engage students deeply enough to help them achieve a meaningful understanding of science (cf., Anderson and Smith, 1987). These observations lead to an obvious question: Why do teachers keep teaching this way? Don't they *know* any better?

This paper focuses on the issue of what teachers know and what they need to know to teach science more successfully. The main section of the paper is devoted to an analysis of the knowledge that underlies successful teaching practice. The implications of this analysis for practice are also considered.

The Knowledge Needed to Teach Science Well

Although the pattern of failure described above is widespread, it is not universal. Some teachers are successful in engaging their students in meaningful science learning. Let us consider a brief episode from the teaching of one such teacher. This teacher, whom I will call Ms. Copeland, taught a seventh grade ecology class in a suburban school district that

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[1]Charles Anderson, associate professor of education at Michigan State University, is a senior researcher with the Institute for Research on Teaching. His research interests focus on classroom science teaching and science teacher education.

served mostly working- and middle-class families (cf., Hollon and Anderson, 1987). The vignette below comes from a unit on photosynthesis. The main point of the unit can be simply stated: Plants use light to make their own food through a process known as photosynthesis. However, easy this may seem, many middle school students (and adults) find this idea and its implications difficult and confusing (cf., Anderson and Roth, in press).

Ms. Copeland's Teaching

The first day of Ms. Copeland's unit focused not on food for plants, but on a topic more familiar to the students: food for people. The students had discussed whether each of a variety of substances could be considered a kind of food. Most substances they had agreed about easily. For example, they had no trouble agreeing that meat and potatoes were food. They also agreed that even though babies sometimes eat dirt, dirt was not food for people. Water, though, was a problem. The students knew that they needed water to survive, yet they would starve to death if they only drank water. Was water a food or wasn't it? Initially, the students were unable to reach consensus about this question.

Ms. Copeland suggested a resolution to the problem based on the scientific definition of food offered in the textbook.

> FOOD refers only to materials that *contain energy* for living things. All living things must use food to grow and keep all their parts working properly. (Roth and Anderson, 1987, p. 16)

Given this definition of food, most students had agreed that water was not food. Staci, however, had continued to argue vehemently that water *was* a kind of food. The issue had not been fully resolved when the first lesson of the unit ended.

Ms. Copeland began the second lesson of the photosynthesis unit with a short review of the previous day's lesson concerning the nature of food for plants and the definition of food as energy-containing matter. Staci, who had argued the day before that water was food, commented:

> Now I'm convinced. The people I polled say you need food and water to survive. . . . I asked my dad and he said food has to have calories so I believe that.

After discussing the role of water, Ms. Copeland posed several questions about how plants obtain food. By now, most of the students had become silent and appeared puzzled by the questions. Ms. Copeland explained that items "like plant food and food sticks make it *sound* like a plant reaches out and munches food."

At this point, Ms. Copeland told students to write down their thoughts about how plants get food and how food moves in a plant. She then asked students to talk about how food moves around inside plants. Several students described food entering through the roots of the plant, from carbon dioxide in the air, and from water in the soil. On the blackboard she wrote, "How Plants Get Food," and listed students' responses. The list included "water from the soil," "carbon dioxide from the air," "soil," "sunlight," "rain," "other plants," "roots and leaves," and "themselves."

It is notable that the list contains several substances, including water, that the class had just decided were not food. To many students, though, this still did not seem unreasonable. Yesterday's discussion had been about food for *people*; this was food for *plants*. Ms. Copeland, however, did not let them off the hook so easily. As they discussed items on the list, she continued to bring up the scientific definition of food from the day before.

T: Look at the list up there. If they get it from the soil, is it like there's little "Big Macs" in there?

S1: It's minerals and nutrients . . .

T: Do minerals supply energy?

S2: Yeah . . . things like potato peels in the soil give it minerals.

T: Do plants *make* the food or are minerals the food? Do minerals supply energy?

S3: Sometimes . . .

T: Does that mean "just on some days"? Anybody think more on that one?

S4: If they supply energy, they'd be food, right? But wouldn't that be the same as saying water is food?

T: How many calories in minerals? Is food for plants the same as food for people? If that were true, all you'd have to do is give them minerals . . .

After discussing each item on the list, Ms. Copeland asked if any of the items were really food for plants. A few individuals insisted that some items were food while others made comments like, "I'm confused . . . where are we?" One student volunteered, "All that stuff just *helps* the plant make its food." Ms. Copeland repeated the statement, emphasizing the words "help" and "make", then repeated the original question about the plant:

T: Where does it get its food?

S: (several call out) They make it!

At this point most of Ms. Copeland's students were on their way to developing a basic minimal understanding of what it means to say that plants make their own food. The unit, however, continued for another week as the students considered an array of related questions: *How* did the plants make their own food? If all those other substances listed on the board were not food for plants, then what *were* they? How did plants use them? Why did plants die in the dark? How was it possible for seeds to sprout and start growing underground, where there was no light? How do humans and other animals depend on photosynthesis?

Ms. Copeland's students figured out the answers to some of the above questions themselves; others were answered initially by Ms. Copeland or by the text. Several questions provoked lively discussions as students worked out for themselves whether the answers made sense and how they were connected with the answers to other, related questions. The students wrote about their ideas and participated in laboratory activities as well as talking and reading. In one activity for example, the students used iodine to test for the presence of starch in various parts of plants, including seeds (such as beans), stems, leaves, and roots (such as potatoes). They then wrote explanations of how the plants had made, transported, and stored the food that they had detected. Although Ms. Copeland treated student ideas with respect, she expected her students, in the end, to produce answers that reflected canonical scientific understanding.

Easy Answers to Hard Questions

What is there to see in the vignette above? What does it tell us about Ms. Copeland and her knowledge of teaching? I believe that most educational professionals--teachers, professors, or administrators--would find aspects of Ms. Copeland's performance that they considered praiseworthy, at least in comparison with the text-dominated teaching that prevails in most science classrooms. Explanations of what is good about her teaching, however, would be many and varied.

Many of those explanations are associated with "catch phrases" that purport to capture the essence of what Ms. Copeland knew or what she was doing. She was engaged in "student-centered" teaching or "inquiry" teaching, she was "teaching process as well as content," she was "using wait time," and so on. The problem with these analyses is not that they are wrong; they often capture something important about the nature of good teaching. At the same time, however, these catch phrases and instant analyses all tend to encourage the belief that there is some relatively straightforward "key idea" that explains Ms.

Copeland's teaching--some small set of prescriptions that would enable other teachers to teach like Ms. Copeland if they would only follow them. In spite of their differences, these analyses all ultimately convey the impression that good teaching is like, say, safe driving: A relatively simple pattern of behavior based on skills and attitudes that teachers could master if they were willing to do so.

Simple characterizations of good teaching may sometimes be useful, but they become troublesome when they are used as a basis for policy. Administrators see little reason why teachers should continue teaching in dull and ineffective ways when more interesting and effective methods are available, so they search for sanctions or incentives that will convince teachers to abandon their hidebound ways, or they try to develop workshops that will train teachers in the skills that they lack. Teachers, in contrast, tend to attribute their failure to teach like Ms. Copeland to factors beyond their control. They must cover so much content that they don't have time for discussions of the students' ideas, for instance, or Ms. Copeland's style of teaching is really more appropriate for students that are older, or younger, or richer, or poorer, than the ones that they are teaching.

The flaw in the reasoning on both sides of these debates lies in the implicit assumption that Ms. Copeland simply "decided" to engage her students in the discussion quoted above, or that she was exercising some generalizable and easily mastered "teaching skills." In fact, what she was doing was more complicated than that. Neither is it true that Ms. Copeland simply possessed some inexplicable talent or personality trait that enabled her to do things that other teachers could not. In fact, Ms. Copeland's "talent" consisted primarily (though not exclusively) of skill and knowledge that she had developed through years of hard work. Ms. Copeland's achievement was more like building a well designed house than like learning to drive safely. It was a complex, multifaceted endeavor that relied on an extensive and well organized body of knowledge.

The complexity of teachers' work and knowledge often goes unrecognized because, unlike houses, the "structures" that teachers build are largely invisible. Nevertheless, they are real and important. The above episode, for example, could not just "happen" in most classrooms. To understand how and why it happened in Ms. Copeland's classroom, we must see that Ms. Copeland and her students acted as they did because they understood this particular discussion to be part of a much larger *pattern of practice* that extended across the school year. Ms. Copeland's pattern of practice was complex and multifaceted. It included the social norms and expectations that prevailed in her classroom, the kinds of work that her students did and her ways of evaluating it, the judgments that she made about what science content to teach and how to teach it, her ways of treating individual students who encountered problems, and many other facets.

The following sections are devoted to explicating the nature of Ms. Copeland's pattern of practice and discussing the knowledge that made it possible. First, I will discuss

the social and pedagogical knowledge that Ms. Copeland used to create and maintain the patterns of social interaction in her classroom. Then I will discuss the nature of the *knowledge of science* and the *knowledge of students* that Ms. Copeland used and communicated in her teaching.

Social and Pedagogical Knowledge

As a teacher, Ms. Copeland functioned as the leader of a "learning community" that operated within her classroom. The participants in this community, Ms. Copeland and her students, had developed shared understandings of their roles and responsibilities, the ways that they should speak and act, the kinds of work that they would do, and so forth. This section focuses on three aspects of life in Ms. Copeland's classroom community: (a) social norms and expectations that Ms. Copeland established in her classroom, (b) the kinds of academic work in which she engaged her students, and (c) the teaching strategies that she used. The section concludes with a discussion of the knowledge that she needed to create and maintain these particular aspects of her pattern of practice.

Social norms and expectations. The first thing that a casual visitor to Ms. Copeland's room might have noticed while watching the events described above might have been that the class seemed enthusiastic, but not completely orderly. Sometimes students called out answers or questions without raising their hands, sometimes more than one student talked at a time. At this level, an observer's evaluation might be based on the relative importance that he or she attached to enthusiasm and order. There is more to see than enthusiasm and order, though. The vignette also provides evidence of other, more subtle norms and expectations that are probably more important in terms of their effects on students' understanding of science.

Consider Staci's behavior, for example. It was interesting and somewhat unusual for a seventh-grade girl. She held on to her opinion against the opposition of her teacher and most of her classmates, continued to discuss the question with other people outside of class, and conceded in the end that she had been wrong all along. This is not typical behavior for 12-year-old girls, who are more likely to avoid intellectual arguments and confrontations with their teachers or their classmates, talk about anything but science outside of science class, and avoid at all costs being wrong when everyone else is right. So why did Staci continue talking outside of class about a scientific question? Why did she not seem embarrassed or concerned when she admitted that she had been wrong? It could be, of course, that Staci was simply unusually assertive and interested in science. There is nothing in the episode, however, to indicate that anyone considered Staci's behavior atypical, and other observations of Ms. Copeland's teaching seem to indicate that several other students besides Staci were *also* unusually assertive and interested in science. Although Staci's behavior would be unusual in other classrooms, it was not in Ms. Copeland's.

In fact, Staci's behavior was part of a normal and expected pattern in Ms. Copeland's classroom. Ms. Copeland had succeeded in creating a social environment where *sense-making* behavior was highly valued, and face-saving behavior was not. Most students believed that science was supposed to be coherent and sensible, for them personally as well as for others, and that they had a right to argue and ask questions if it did not. In Ms. Copeland's class these questions and arguments were perceived as worthwhile and enjoyable, and it was recognized that a cogent defense of an incorrect position might contribute more to the individual and collective sense making of the class than simply knowing the right answer. Correct answers were important, but so were good questions and good arguments, especially good arguments that helped clarify the reasoning behind the correct answers.

Academic tasks. Walter Doyle (1986) argues that teachers inform students about their curriculum--their goals and expectations for student learning--primarily through their accountability systems. To know a teacher's *real* curriculum, Doyle argues, we should look not at formal statements of goals and objectives but at the *work* that students are engaged in and the ways that the *work* is evaluated.

What sorts of work were Ms. Copeland's students engaged in and what did that reveal about her curriculum? At a superficial level, the academic work in her class seems pretty ordinary: Class discussions, worksheets, laboratory activities, and so forth. At a deeper level, though, there were important differences between her students' work and the work of students in other science classrooms. Her students rarely copied facts and definitions or answered questions about laboratory procedures. Instead, there was a heavy emphasis in their work on *using* scientific knowledge, particularly to explain how and why things happen in the natural world. Which direction does food normally travel in the stem of a plant? Why do green plants die in the dark? What will happen to a raindrop that soaks into the soil around a large bean plant?

By way of comparison, consider the academic work associated with the chapters of photosynthesis in typical life science textbooks:

> The method of making food by storing light and energy is called _ _ _ _ _ _ _ _ _ _ _ _ _ _ _. (McLaren, Stasik, and Levering, 1981, p. 55)
>
> Plants usually get their food
> a. by absorbing it from the soil directly
> b. from fertilizers that are found in organic material
> c. from other plants and animals
> d. by absorbing minerals and water and then making food (Oxenhorn, 1981, p. 74)
>
> What conditions are necessary in order for a leaf to carry on photosynthesis? (Kilburn and Howell, 1981, p. 390)

Thus teachers who wish to teach for understanding must learn to reject or modify the academic tasks supplied to them in most textbooks and other teaching materials. These "teaching aids" support a kind of teaching that leads to rote memorization of facts and definitions, not teaching that helps students deepen their understanding of the natural world.

Teaching strategies. Textbook developers have good reasons for providing academic work that consists primarily of relatively easy but useless questions. The most important of these reasons is consumer demand: Many teachers *want* textbooks with these sorts of questions and would reject academic tasks like those used by Ms. Copeland as "too difficult" for their students. In a sense, they are right; most students cannot learn to answer questions like those that Ms. Copeland focused on without the help of sophisticated and demanding teaching strategies. Such teaching strategies are neither new nor unknown. In fact, many people who have no training in professional education routinely use strategies more sophisticated and effective than those employed by most science teachers. Examples from out-of-school contexts include masters working with apprentice craftsmen (Collins, Brown, and Newman, in press) and mothers teaching their toddlers how to speak (Greenfield, 1984).

Collins, Brown, and Newman (in press) point out that such successful everyday learning situations have a number of common features. They occur within the context of a "culture of expert practice" where the learners are strongly motivated to master come skills or tasks that will help them become full-fledged members of that culture. Teachers and learners together generally work their way through a succession of activities in which responsibility of doing the task gradually passes from the teacher to the learner. Collins, Brown, and Newman summarize this sequence as *modeling* (the teacher does the task while the learner observes), *coaching* (the learner does the task with support and guidance from the teacher), and *fading* (the learner gradually assumes full control).

As Collins, Brown, and Newman (in press) point out, making teaching strategies like these work in a public school setting is fraught with difficulty. It is much easier to establish a "culture of expert practice" in an environment where "experts" outnumber learners than in a school setting, where learners are a large majority. The students often are not strongly motivated to learn in public school settings. In contrast to the visible activities of children learning to speak or apprentices learning a craft, students in a science classroom are learning patterns of thought and reasoning that are often silent and invisible. Thus Ms. Copeland's achievement was a considerable one. She created a social environment where students were intrinsically motivated to learn science and where they were willing to express their thoughts. When students "made their thoughts visible" to the class, Ms. Copeland could help them see the strengths and weaknesses in their thinking and engage in the modeling, coaching, and fading of canonical scientific reasoning.

Ms. Copeland's social and pedagogical knowledge. This section has been devoted to describing what Ms. Copeland *did* as she taught her unit on photosynthesis. The pattern of

Ms. Copeland's practice included the social environment that she created in her classroom, the academic work that she engaged her students in, her teaching strategies, and much more. To describe this pattern of practice, however, is not to say what Ms. Copeland *knew* that made it possible for her to create and maintain it.

Describing Ms. Copeland's social and pedagogical knowledge is difficult in part because her knowledge was personal and context-bound in at least two senses. First, her knowledge was tied to her particular teaching situation. The evidence for the extent of her knowledge takes the form of her success in developing a rich and effective pattern of practice with those particular students, in that particular course, using the particular teaching materials and other resources available to her at that time. It is hard to say to what extent Ms. Copeland knew how to develop this pattern of practice in a more general sense.

Ms. Copeland's social and pedagogical knowledge was also personal and context-bound in that it was largely tacit knowledge; she lacked a language or a set of categories to describe and explain what she knew. The language of simplistic solutions that prevails in workshops and methods courses is obviously inadequate to describe what Ms. Copeland knew and did. So is the language of the "teaching suggestions" in the teacher's editions of textbooks. We don't really know very much about how Ms. Copeland developed the tacit knowledge that she used to lead her classroom community, develop academic tasks, and decide on teaching strategies. We believe that, like most teachers, she had no choice but to develop this knowledge largely through reflection on her own teaching experience.

Although this method of developing knowledge seems to have worked reasonably well for Ms. Copeland, there are two important reasons for believing that it is not working very well for the profession as a whole. The first is obvious: Without more effective forms of support most teachers fail to develop patterns of practice as sophisticated or as effective as Ms. Copeland's. The second is more subtle: The absence of an adequate language for organizing and expressing their knowledge of practice condemns each generation of science teachers to rediscovering the knowledge of their predecessors through personal experience rather than building on the knowledge of previous successful science teachers.

Knowledge of Science

As a teacher Ms. Copeland was poised between two subcultures: an adult subculture of scientists and their work and a very different subculture of the twelve-year-old children in her classroom. Her job was to transform the children, to make them somehow more like scientists than they were before they came to her. This left Ms. Copeland with a great many choices about what to teach, for her children were unlike scientists in a great many ways. It also left her with an immense problem, because the scientific subculture in its adult form is distant and inaccessible to most students. Scientists have access to a vast and complex body of knowledge that they communicate to each other in an arcane jargon full

of technical terms. They work in ways that require a great deal of knowledge and technical skill, and often immense patience and perseverance, trying to answer questions that are often themselves incomprehensible to children.

Thus in order to transform her students Ms. Copeland had to transform science. She had to create a body of scientific knowledge and a version of the scientific subculture that were accessible to her students. In transforming science Ms. Copeland had to deal, at least implicitly, with some difficult and philosophically profound questions: What *is* science and what are its component parts? Out of the entire scientific enterprise and its products, what is important for seventh-grade to learn now and what can wait until later? What is comprehensible to twelve-year-olds and what is beyond their reach?

It is possible, of course, to teach science without thinking explicitly about the above questions at all. Teachers have access to a variety of materials that provide, or purport to provide, ready-made answers; foremost among these are textbooks and curriculum guides. Unfortunately, there many reasons to question the adequacy of the textbooks' representation of the scientific enterprise, including the statistics on students' learning at the beginning of this paper. Science as represented in most textbooks seems to be pretty dull and disconnected stuff, certainly not something that most children would want to find out about in their spare time. Even more troubling, the culture of most classrooms where those textbooks are used has little in common with the culture of adult science. Most adult scientists, for example, spend relatively little time copying facts and definitions out of books, yet that is the primary activity of many students in science classes. For many children, exposure to science textbooks and to the culture of science classrooms results not in understanding but in alienation from science.

Ms. Copeland's classroom and some other classrooms demonstrate that this alienation is not inevitable. It is possible to construct learning environments that represent the culture of science in a rich, full, and interesting way. Ms. Copeland succeeded in helping her students to see how science incorporates a useful and coherent body of knowledge, and she constructed a classroom environment that conveyed something of the nature of science as a social enterprise. Each of these characteristics of her teaching is discussed below.

Scientific knowledge as useful. Textbooks typically depict scientific knowledge as consisting of "content"--an array of facts, definitions, formulas, and so forth--and "process skills" that scientists use then they are discovering new content. Both parts of this depiction are troublesome. There is strong reason to doubt whether science process skills exist at all, at least as the generalizable and content-free skills often depicted in the science education literature (Kuhn, Amsel, and O'Laughlin, 1988; Millar and Driver, 1987). As for content, the typical textbook depiction of science makes it hard to understand what makes all those facts and definitions worth knowing. The textbooks are full of answers, but they generally fail to

inform their readers about the questions that scientists were asking when they invented those answers.

What is missing, in other words, from the textbooks' depiction of science content is a sense of why scientists seek their knowledge and what they do with their knowledge once they have it. Scientific knowledge provides us not just with statements about the nature of the world, but with a wide array of conceptual and technological *tools*. People who use these tools--the language, theories, and instruments of science--are capable of describing, explaining, making predictions about, and controlling the world with a precision, power, and depth of understanding that would be otherwise impossible. For example, the idea that plants use light to make their own food can be treated as a simple statement of fact; this is what most textbooks (and most science teachers) do. Used as a tool, however, this same idea can help to explain many things about green plants: Why they have leaves, why their leaves turn toward the sun, why they die without light, why animals depend on them, and so forth. Furthermore, the tools of science provide those who master them with access to the community of scientists and to the knowledge and power that community possesses. There is no clear line of demarcation between "scientific" and "unscientific" description, explanation, prediction, and control. People engage in these activities scientifically to the extent that they use the conceptual and technological tools of science to increase the power and precision of their performance.

These thoughts suggest a view of the science curriculum in which students develop a progressively deeper understanding of science by engaging in activities that use scientific knowledge as a tool. Children entered Ms. Copeland's class already describing, explaining, predicting, and trying to control the world around them, though often in ways that lacked power and precision. Ms. Copeland gave her students opportunities to increase the power and precision with which they engaged in these important activities, rather than limiting them to less significant activities such as recalling facts.

In contrast, many other science teachers teach students about the conceptual tools of science without teaching them how to *use* those tools. In these classrooms, students are generally exposed to large numbers of facts and vocabulary words, tested for recall, and moved on to the next topic (cf. Eaton, Anderson, and Smith, 1984; Hollon and Anderson, 1987). The facts and vocabulary words are considered to be "understood" when students can associate them with other facts, definitions, or vocabulary words. They are rarely used for the purposes of describing, explaining, predicting, or controlling the real world. This instructional pattern is sometimes justified, implicitly or explicitly, by the assertion that students need to learn "basic facts" before moving on to "higher order thinking." Teachers argue that they can expose students to these facts and concepts early on, but that students will develop meaningful understandings of these ideas only later, when they are capable of abstract thinking.

This reasoning is an empty rationalization. Children begin to engage in the activities labeled as "higher order thinking"--description, explanation, prediction, and control of the world around them--*before* they learn to memorize facts and reproduce them on demand. Students who are made to memorize and reproduce facts are practicing an activity that has little in common with meaningful uses of scientific knowledge and which does little to prepare them to use scientific knowledge meaningfully.

A common instructional pattern in the classrooms of skilled and experienced science teachers is one in which the *teacher* uses scientific knowledge meaningfully during lectures and discussions, but not the students. The students witness the teacher's performance and often participate in it in a limited way, providing important words or bits of information as requested by the teacher. However, their independent academic work still consists primarily of producing small bits of information on demand. Consider, for example, the way one such teacher, whom we shall call Mr. Barnes, taught the same lesson on photosynthesis as Ms. Copeland. Like Ms. Copeland, he made a list on the board of students' ideas about where plants get their food. The discussion then proceeded as follows:

T: Let's go back to what we talked about yesterday. We said, we gave a definition for food. What was the definition of food?

S: Energy? Anything you can eat that is energy?

T: All right. In talking about food for ourselves, we say it's the things that we eat but it's to obtain energy for life processes. (Writes on board: Food: Materials that contain energy to help living live and grow.) That's close . . . on p. 2 they gave a definition (he reads it aloud) . . . So that's pretty close to a scientific definition of food.

S: You left "things" out.

T: Yes. We could say "organisms." If a plant is a living thing. . . . Is a plant a living thing?

S: (several nod yes)

T: Sure, we all understand that plants are living things. If a plant is a thing, then it has to use some food for energy. What they want you to struggle with is where do they get food from. All too often we're brainwashed--the stuff we get from the store is labelled "plant food." That does help plants grow but does it contain energy?

S: (very quietly) No.

T: It's hard to visualize whether it does contain energy. It does seem to help plants grow. But it's like vitamins. . . . We came to this conclusion yesterday, didn't we? That vitamins don't give us energy but do help us live and grow. It's the same situation with plant food, the stuff we buy at the store. It's improperly labelled. They're fertilizers that help the plan grow but the don't contain energy. (pointing to "minerals" on the students' list on the board) Minerals from the soil are fertilizer types of stuff but there's not really energy in minerals you get from the soil. (Pointing to "air" on the list on the board) The air does contain things that plants use but they really don't contain energy. Yesterday we saw a filmstrip. Anybody remember where did all the energy come from that plants were using?

The same general pattern prevailed in most of Mr. Barnes' classes. He told his students much more about plants and photosynthesis than Ms. Copeland. Furthermore what he told them was generally accurate, well organized, and modeled the usefulness of scientific knowledge. Nevertheless, Ms. Copeland's students did better on a posttest assessing their understanding of photosynthesis.

These results are in keeping with a general pattern (cf. Anderson and Roth, in press): In order to master new scientific knowledge, most students need to *use* that knowledge themselves to make sense of the world around them. By helping her students to do this, Ms. Copeland conveyed to them a powerful and effective message about the particular scientific ideas that they were studying and about the nature of science in general.

Science as coherent. It is notable in the vignette of Ms. Copeland's teaching that the primary language of discussion is the language of the students, not the specialized language of science. The class discussed "food," "calories," and "potato peels" rather than "organic compounds," "chemical potential energy," and "carbohydrates." In doing this she seemed to sacrifice much of the power and precision of scientific language. She made this sacrifice, however, in order to represent science faithfully in another, more important way.

Ms. Copeland's willingness to use her students' words when talking about science was one of several ways in which she made them aware that scientific knowledge is strongly connected with their personal knowledge of the world. She helped her students to see science not as a list of strange and obscure facts but as a coherent conceptual system that was linked to the students' "common sense" understandings. Students should expect the two types of knowledge to fit together into a single integrated understanding of the world.

Ultimately, the coherence of scientific knowledge can be fully expressed only in the specialized language, verbal and mathematical, of science. Ms. Copeland recognized this and devoted much of her time to helping students understand new words, such as "photosynthesis" and scientific usages of familiar words, such as food or energy. Unlike Mr. Barnes, though, who tended to use a lot of scientific terms to maximize the coherence of his

own presentations, Ms. Copeland used fewer scientific terms sought to maximize the coherence of her students' understanding.

Science as a social enterprise. Recent work in the history and philosophy of science (Kuhn, 1970; Mayr, 1982; Toulmin, 1961, 1972) depicts scientists as engaged in a collective attempt to understand the natural world. They constantly search for new and more powerful ways to understand and control the world. Scientists who believe that they have developed some new knowledge communicate that knowledge to the community of their peers, and the knowledge is considered valid only after it has been reviewed and accepted by that community. No individual scientist knows all that is known about a topic; the growing body of scientific knowledge is the product, and the possession, of the entire scientific community.

In her classroom Ms. Copeland created an environment where students felt that, like scientists, they were engaged in a process of collective sense making. Their high level of involvement can be explained by the fact that within her classroom the students, not the teacher or the textbook, were the ultimate arbiters of new knowledge. New ideas from any source--the teacher, the textbook, or the students themselves--were subjected to "peer review" by the students. Most students undoubtedly realized that the ideas in the textbook would "win out" in the end, but they also understood that that was not really the point. They were enthusiastic in accepting their right, and their obligation, to demand that any new idea make sense to them, be useful to them, and be integrated into the growing body of their own scientific knowledge. Ms. Copeland recognized and rewarded the contributions of students who, like Staci, could mount sustained and reasonable defenses of incorrect points of view. She did so because arguments like Staci's were valuable to the sense-making enterprise of the students as individuals and of the classroom community as a whole.

The ideas that in learning science students should "act like scientists" is not a new one. It was the basis for the development of "discovery" or "inquiry-oriented" science programs during the 1960s. The failure of those programs (cf., Roth, 1984; Smith and Anderson, 1984) can, I believe, be attributed in part to two related factors. First, the inquiry programs concentrated on imitating the procedures that individual scientists follow in their laboratories rather than on the collective sense-making functions of scientific communities. Second, students in inquiry programs were often given few opportunities to use their scientific knowledge or to connect it with their own personal beliefs about the world. Thus the "hands-on" activities of inquiry programs imitated the form of scientific research, but I believe that Ms. Copeland's class activities came closer to representing its underlying substance.

Ms. Copeland's knowledge of science. Ms. Copeland chose to present science to her students in a way that emphasized some aspects of the scientific subculture, especially its individual and collective sense-making functions, while deemphasizing traditional "content" and "process" goals. Some educators, especially those who are highly scientifically literate

like Mr. Barnes, may regard this as basically a value judgement, a choice among alternative reasonable goals. However, there is a growing body of empirical evidence (reviewed in Anderson and Smith, 1987) that this is not the case. Ms. Copeland's students did not just learn *different* knowledge, they learned *more*. Most students simply cannot make sense of and remember science as it is typically taught. Thus it is incumbent upon the education community to help more teachers learn how to present science as Ms. Copeland did.

Clearly, Ms. Copeland could not have taught as she did without knowing quite a bit about science. What she knew, however, was not the same as the "science" included in most science textbooks. Neither was it the same as (or a subset of) the science taught in most university science courses. University science courses are designed to provide an insider's view of science: to help induct new members into the scientific subculture, to prepare college students to communicate with scientists in their language and work with scientists on their terms.

Ms. Copeland, however, was not communicating and working with scientists; she was communicating and working with children. Rather than acting as a member of the scientific subculture, she worked as a mediator between the subculture of science and the very different subculture of children. Thus the nature of their work demands that Ms. Copeland and other science teachers develop an outsider's as well as an insider's view of science. They must decide what is essential to the scientific enterprise and what is peripheral, which aspects of scientific thought and language are accessible to the children they teach and which are not, how scientific thinking is like their students' thinking and how it is different.

Like her knowledge of practice, that portion of Ms. Copeland's knowledge of science that went beyond what it taught in science courses was largely a personal construction, knowledge developed in response to the problems that she experienced while trying to teach middle school science. The curriculum materials that were supposed to support her in this aspect of her work provided little useful guidance; they tended to focus on the superficial form of the scientific enterprise rather than its underlying substance: the collective search for coherent and useful knowledge of the natural world. Most universities offer courses that address these issues, but they tend to be hidden away in subdisciplines such as the history and philosophy of science that are not usually viewed as relevant to the training of teachers. Ms. Copeland was able to overcome these difficulties and construct in her classroom a rich and meaningful representation of the scientific enterprise. Most teachers, unfortunately, are not.

Knowledge of Students

The essence of Ms. Copeland's job was transforming students--or more accurately helping them to transform themselves--into people who are more scientifically literate than they were before they came to her. She could not do this job well without knowing quite

a bit about her students and how they understand the world. This knowledge included both an understanding of how her students think about specific science topics and an understanding of how her students' learning of science is influenced by more general social, cultural, and economic factors.

Students' knowledge of specific scientific topics. In order to understand science meaningfully, students must connect canonical scientific knowledge with their own personal knowledge of the world. Students who fail to do so end up viewing science as a collection of facts, definitions, and formulas that are about topics too distant from their own lives to have any personal meaning or significance. Too often, this is exactly the kind of learning that occurs in science classrooms. It is often hard to see how scientific knowledge connects with students' personal beliefs about the world. Most of Ms. Copeland's students, for example, knew little or nothing about photosynthesis *per se* before she began teaching them about the topic.

This does not mean, however, that the students had no relevant prior knowledge. In fact, the vignette from Ms. Copeland's teaching shows that the students had lots of ideas about food, and about plants, and about food for plants (see also Anderson and Roth, in press). Some of these ideas were useful and scientifically correct: The association between food and energy (or calories), for example. Other ideas were incompatible with canonical scientific knowledge, such as the students' tendency to associate food and eating. Middle school students know that food is what you eat. They reason, therefore, that food for plants is what plants "eat": Water and soil minerals (or "plant food").

The students' beliefs about plants' structure and function showed a similar mixture of scientifically acceptable and unacceptable beliefs. Most middle school students, for example, understand that plants are living organisms. Thus they naturally try to understand how plants work by analogy with more familiar organisms, such as animals. In their attempts to make plants comprehensible, they reason that they must engage in functions similar to those of animals, including eating and digestion.

Thus to understand photosynthesis, students must go through a complex process of conceptual change. They must abandon their assumptions about the metabolic similarities between plants and humans and restructure their thinking about the nature of food. Without this involved process of restructuring and integration of personal knowledge with scientific knowledge, students cannot be successful in using knowledge about photosynthesis to make reasonable predictions and explanations of real-world phenomena. In order to help her students transform their thinking, Ms. Copeland had to guide them through the conceptual change process.

Social and cultural influences. From the time of its origins in the 17th century through the mid-19th century, modern science was virtually the exclusive province of upper class, western European, white males, mostly men of independent means who could practice

science without outside financial support. Naturally, these men tended to make science in their own image, depending on the patterns of thought and language and the assumptions about the relationship between man and nature that were most comfortable and familiar to them.

There can be no doubt that these men succeeded in constructing a body of knowledge that has significance for all humans. People of all cultures have accepted the validity and importance of Western science and have set about trying to master it. In contrast, Western views of history, or religion, or political philosophy have gained far less universal acceptance. At the same time, though, modern science retains some of the marks of its origins, and this is a problem for teachers of socially and culturally diverse groups of students.

For example, Keller (1985) points out that modern science still tends to rely on metaphors and modes of thought that are associated with masculinity in our society. Many scientists continue to be interested in finding ways of controlling nature and of discovering the laws to which "she" is subject. Warmth, empathy, and love are regarded as dangerous emotions, as threats to the skepticism and cool objectivity that are necessary for the development of reliable scientific knowledge. Thus many girls get the subtle message that to be feminine and to be scientific are mutually exclusive alternatives.

Differences in language and culture can also affect the ease with which students master scientific reasoning and knowledge. Some of these difficulties may be quite specific. For example, Orr (1987) argues that students who speak Black English Vernacular often use "function words" such as prepositions and conjunctions in nonstandard ways, and that these nonstandard usages influence the way that they understand, and are understood, when they are dealing with quantitative problems expressed in standard English.

Other culture-related difficulties are more general in nature. For example, there is a large and complex literature on the effects of culture and literacy on patterns of reasoning (cf., Egan, 1987; Olson, 1986; Scribner and Cole, 1983). This research indicates that the patterns of our reasoning are influenced by the culture in which we are raised. Egan, for example, uses historical and anthropological evidence to contrast "literacy" and "orality" as alternate ways of knowing, each embedded in a rich cultural context. He notes, for example, the explanatory challenge posed by the Homeric epics. How could Homer (who was apparently illiterate), have constructed such a complex and extensive work of art? How could he even *remember* a sequence of works more than 28,000 lines long? Recent archeological evidence indicates that many of the events described in the *Iliad* actually occurred. How did an illiterate society keep this memory intact for half a millennium?

Egan responds that the Homeric epics, and similar myths in other oral cultures, were far more than just stories; they were the "libraries" of oral societies, the repositories of the accumulated knowledge of those cultures. The framework of the epics' story lines and a variety of technical devices, including rhyme, meter, and an array of repeated phrases, made

it possible for illiterate poets not to remember a fixed text, but to "stitch together" their poems as they sang. In this way, the members of oral cultures could routinely perform what seem to us extraordinary feats of memory and preserve the accumulated knowledge of their cultures.

The knowledge accumulated by oral cultures took a form, however, quite different from knowledge as we think of it today. There were no clear divisions between fact and fiction, between myth and reality, between stories and theories. These sorts of distinctions, as well as innovations such as syllogistic reasoning, were made possible by the development of writing as an alternate form of memory and our resultant freedom to manipulate and analyze texts and ideas. Egan makes this point by quoting a passage from Levi-Bruhl on the oral peoples that he studied:

> This extraordinary development of memory, and a memory which faithfully reproduces the minutest details of sense-impressions in the correct order of their appearance, is shown moreover by the wealth of vocabulary and the grammatical complexity of the languages. Now the very men who speak these languages and possess this power of memory are (in Australia or northern Brazil, for instance) incapable of counting beyond two and three. The slightest mental effort involving abstract reasoning, however rudimentary it may be, is so distasteful to them that they immediately declare themselves tired and give it up. (Levi-Bruhl, 1910/1985, p. 115)

Egan argues that orality did not disappear with the advent of literacy; modern cultures are complex mixtures of oral and literate traditions. Western science is, of course, the product of a highly literate class within a literate cultural tradition, so it depends strongly on literate rather than oral modes of thinking. Thus in scientific contexts, myth, metaphor, and story telling are devalued, while literate modes of thought involving clear distinctions and syllogistic reasoning are highly valued. This can be a problem for students whose own cultural traditions have strong oral roots.

The purpose of this argument is to suggest that science has deep-seated characteristics that tend to make it more easily accessible to men then to women and more easily accessible to people who were raised in highly literate environments. Thus, at present, our schools succeed in teaching science to those students whose cultural roots are most compatible with the culture of science. We have an obligation, though, to nurture the scientific understanding of students whose social and cultural backgrounds are less easily compatible with the values and habits of thought characteristic of the scientific subculture.

Ms. Copeland's knowledge of students. Both Ms. Copeland's teaching and our interviews with her revealed that she knew a lot about her students and their thinking. She was able, for example, to predict in considerable detail how they would respond to questions about the nature of food and the functioning of plants, even before she began teaching the

unit. Like her knowledge of practice, though, her knowledge of students was mostly personal and context-bound. She had developed this knowledge through her reflection on experience, with little help from teacher's guides, her university courses, or inservice teacher education programs.

This was true in spite of the fact that the past decade has seen a revolution in our research-based understanding of students and their scientific thinking (cf., Novak, 1987; Osborne and Freyberg, 1985), as well as research like that cited above concerning the effects of culture on knowledge and reasoning. The products of this research, though, are still mostly hidden away in the research literature and in graduate courses; they have so far had little influence on the developers of teaching materials or on the education of intending or inservice teachers.

Implications for Policy

This paper focuses on the question: What do teachers need to know in order to teach science well? In the introduction to this paper I compared science teaching to building a house, suggesting that both were complex, multifaceted achievements requiring an extensive and well-organized body of knowledge. The main body of the paper has been devoted to explaining the nature of this achievement for one good science teacher and to discussing the knowledge that made her achievement possible. The main point of this discussion is that successful teaching requires a *lot* of knowledge about social arrangements in classrooms, about pedagogy, about science, and about students. I would now like to return to the house-building analogy in order to make a second point: Although achievements like house building and science teaching always require a lot of knowledge, the exact nature of the knowledge required depends on the context in which people work and the tools that they use.

Consider two extended "case studies" of house building: Laura Ingalls Wilder's description of how her father built a log cabin in *Little House on the Prairie* and Tracy Kidder's (1985) account of the building of a house in modern New England. The building of both houses required knowledge and skill. Here is an excerpt from Wilder's account of how her father made the floor of their cabin:

> One day the last log was split, and next morning Pa began to lay the floor. He dragged the logs into the house and laid them one by one, flat side up. With his spade he scraped the ground underneath, and fitted the round side of the log firmly down into it. With his ax he trimmed away the edge of bark and cut the wood straight, so that each log fitted against the next, with hardly a crack between them.
>
> Then he took the head of the ax in his hand, and with little, careful blows he smoothed the wood. He squinted along the log to see that the surface was

> straight and true. He took off last little bits, here and there. Finally he ran his hand over the smoothness, and nodded. "Not a splinter!" he said. "That'll be all right for little bare feet to run over."
>
> He left that log fitted into its place, and dragged in another. (Wilder, 1935/1971, pp. 128-129)

By way of comparison, the following passage describes how Jim Locke planned the support structure for the floor of the Souwaine house.

> He has to decide where to put a lot of sticks, so that the fewest possible are used and the least amount of cutting is required. Plywood comes in four-foot-by-eight-foot sheets. He has to make sure that the floor joists are spaced in such a way that two edges of every sheet of plywood come to rest on something solid. He also has to determine exactly the boundaries of each room because some will be floored with oak, some with tile, some with carpeting, and each of those surfaces calls for a different quality and thickness of plywood. The trickiest part, though, is the girders, the beams they'll make to hold up the floor joists. Bill wants a sunken floor in the living room. At one edge of that room a very heavy hearth occurs. In essence there's a place where floors of three different levels will meet. Jim stacks one set of girders onto another, and goes on. One section of floor is a little too wide for those joists. Or he could use two-by-twelves of spruce. Or he could use Douglas fir two-by-tens. Which is cheaper? Which takes less time to install? Jim has settled on Douglas fir. It comes from the Pacific Northwest. His supplier has to order it specially, and Jim hopes that it will arrive on time. (Kidder, 1985, pp. 85-86)

As Resnick (1987) suggests, the knowledge that Charles Ingalls needed in his head and his hands is now built into the tools and materials that are routinely available to modern house builders. This does not mean that house building is now simple. Rather, by developing tools, materials, and support systems that were not available to Charles Ingalls, we have made it possible for modern house builders to construct houses that are far more complex, and far more comfortable, than the Ingalls' little log cabin. In the process, we have changed the nature of house builders' work and the knowledge that it requires.

Thus there can be no single answer to the question of what teachers need to know to teach science well. It will always depend on the nature of the contexts in which they work and the tools and materials available for them to use. I have suggested in this paper that Ms. Copeland's work was more like Charles Ingalls' house building than like the house building process described in Kidder's book. In building her pattern of practice, Ms. Copeland was faced with a constant struggle to compensate for the deficiencies of the materials that she was using and the training that she had been given. It is still necessary for teachers like Ms. Copeland to devote much of their knowledge, time, and energy to

doing this; I am not sure that the solution to our problems in science education lies mainly in trying to train other teachers to do the same.

The challenge that we face is not simply one of finding talented teachers or of improving science teachers' skills or attitudes. We must find ways of helping thousands of science teachers build patterns of practice that are more sophisticated and more effective than those that prevail today. Among the many science teachers that my colleagues and I have observed in our research and teacher education work, Ms. Copeland stands out as a rare (though not unique) exception. Most of the teachers we have seen have been sincere, hard-working people who developed patterns of practice that were far less functional than Ms. Copeland's. In the main, they succeeded in keeping their students well organized and busy and in helping their students to memorize some facts and definitions, but they failed to help their students make sense of the facts they memorized (cf., Anderson and Roth, in press; Anderson and Smith, 1987; Hollon, Anderson, and Roth, in press).

The situation is not a "crisis," it is simply the way things are. It is not primarily the fault of science teachers any more than it was Charles Ingalls' fault that his house lacked running water. Like builders' work, teachers' work is shaped by the knowledge that they possess, the context in which they work, and the available tools and materials. The knowledge, contexts, tools, and materials of science teachers' work currently support the maintenance of order and the memorization of facts. Many science teachers try to do more, to teach for understanding. To do more, however, is currently a very complex and difficult task. Only a few exceptional individuals are truly successful.

Teaching science for understanding is currently so difficult because it requires a pattern of practice based on knowledge that most teachers do not have, including social and pedagogical knowledge, knowledge of science, and knowledge of students. I do not think that there will ever be more than a few teachers who, like Ms. Copeland, manage to successfully develop and use that knowledge on their own. They should not *have* to do it on their own, though. Jim Locke could build a better floor than Charles Ingalls because the knowledge of many people, some of them long since dead, was built into the tools and materials that he used, and because he was supported by many people--architects, plumbers, electricians, and so forth--who had knowledge that he lacked.

Many other crafts and professions have also developed successful mechanisms for preserving and sharing important knowledge: Farming, medicine, and engineering, for example. In contrast, we in the education profession have not been particularly successful at preserving and sharing knowledge. Teachers like Ms. Copeland must develop much of their knowledge through personal experience, and they must learn how to modify or ignore inadequate tools and materials. There is often not even a language that they can use to express what they have learned and share it with other teachers.

Changing this system for the better will be a long and difficult process, a process that spans generations rather than years, a process composed of thousands of small improvements in the knowledge and practice of individual science teachers. Policymakers cannot make this process happen, but they can encourage the development of better knowledge and more sophisticated patterns of practice. Ways in which policymakers can encourage the development and use of a better knowledge base include the following:

1. **Improving teaching materials.** Most current teaching materials are woefully inadequate; they are tools which are not well suited to teaching for understanding and which fail to incorporate important knowledge. It is possible, though time-consuming and expensive, to develop teaching materials that give teachers access to important knowledge and support effective patterns of practice (cf., Anderson and Roth, in press; Driver, 1987; Linn and Songer, 1988). It will be difficult and risky for commercial publishers to develop materials like these. They are likely to attempt to do so only in response to strong market pressures. By letting publishers know that they are paying attention to ways in which teaching materials incorporate worthwhile knowledge and support good practice, policymakers can begin to supply the necessary market pressure.

2. **Teacher education.** The bulk of this paper has been devoted to describing the social and pedagogical knowledge, knowledge of science, and knowledge of students that good science teaching demands, but that is currently missing from most preservice and inservice teacher education programs. We do not need more (or less) of the kinds of courses that we have now; we need courses that provide teachers with different kinds of knowledge. We believe that we know enough now to make significant steps toward developing such programs, and we have experienced some success in our teacher education work (cf., Hollon, Anderson, and Roth, in press; Roth, Rosaen, and Lanier, 1988).

3. **Assessment and accountability.** It appears that, for better or worse, large-scale systems of teacher and student assessment are here to stay. It is important to recognize their limitations; teachers cannot be forced to engage in patterns of practice for which they lack the knowledge, the tools, or the time. It is possible, though, for systems of student assessment to encourage teaching for understanding and for systems of teacher assessment to encourage the development of sophisticated and effective patterns of practice. Some promising development work on such systems is underway (cf., Anderson, 1988; Fredrickson, 1984; McDiarmid and Ball, 1988; Sykes, 1989). Policymakers can be aware of this work and use it.

4. **Time.** It takes time to teach well: Time to plan, time to respond to student work, time to develop new knowledge. The teaching loads that currently prevail in our schools deny teachers that time and thus work against the improvement of science teaching.

The changes suggested above are not "practical" in that they suggest fundamental and sometimes expensive changes in our science education system. Decisions about what is

practical, though, need to be made with consideration of their long-term effects. The statistics at the beginning of this paper indicate that millions of students are currently wasting their time, learning virtually nothing of value in their science classes. What could be less practical than the years of quick fixes that have helped to create this situation? The experience of other professions indicates that many small improvements can have a large cumulative effect over time. This happens, however, only if those small improvements are guided by some sense of shared purpose or direction. A determination to help science teachers gain access to and use new knowledge to develop more effective patterns of practice could help to provide our profession with such a sense of shared purpose.

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WHAT TEACHERS NEED TO KNOW TO TEACH SCIENCE EFFECTIVELY

Anton E. Lawson[2]

I find myself in substantial agreement with the remarks made by Charles Anderson. However, before proceeding with my answer to the question, "What do teachers need to know to teach science effectively?" I feel compelled to comment on two points made by Anderson.

First, in my opinion Anderson's statement that "There is strong reason to doubt whether science process skills exist at all" is clearly in error. The issue is not whether science process skills exist. Rather, key issues center around the explication of their precise nature, their articulation with specific subject matter, and their means of acquisition. Considerably more will be said about this later, including a list of seven basic science process skills and numerous subskills.

Second, Anderson's claim that the "inquiry-oriented" programs of the 1960s were failures is, at best, very misleading. The only failure that can reasonably be attributed to these programs is that most teachers do not use them, and that some who do, do not use them correctly (e.g., Hurd, Bybee, Kahle, and Yeager, 1980). When these programs are used correctly, they are overwhelmingly successful. Shymansky (1984), for example, reported the results of an analysis of over 302 research studies in which "traditional" programs versus the inquiry-oriented science curricula of the 1960s-1970s were compared. Result of the analysis showed that the inquiry-oriented curricula were superior across *all* measures of performance. The positive effect for the Biological Sciences Curriculum Study (BSCS) high school biology program was most impressive. The average BSCS student outscored 84 percent of traditional course students on attitude measures, 81 percent on process skills, 77 percent on analytic skills and 72 percent on concept achievement.

Further, Lawson, Abraham, and Renner (1989) recently reviewed nearly 100 studies of science programs such as the Science Curriculum Improvement Study (SCIS) K-6 elementary school program. The SCIS program was developed with National Science Foundation support during the 1960s and 1970s and utilizes the inquiry-oriented learning cycle method of teaching. The Lawson, Abraham, and Renner review clearly reveals the success of the SCIS program and the learning cycle method. Students using the program and/or this teaching method have a more positive attitude towards science, they better understand the nature of science, they successfully acquire important science concepts, and their science process skills (i.e., general thinking skills) are significantly enhanced to the

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point at which performance in other subjects such as mathematics, social studies, and reading are also enhanced. This is hardly a failure.

The only failure that I can see in all of this is that policymakers in this country have not pushed hard enough to have these excellent programs adopted or, when adopted, have not insisted that teachers teach them as they were designed to be taught. Getting back to Anderson's claim that these programs were a failure, it should be pointed out that he supported this contention with reference to a study by Smith and Anderson (1984). But the failure referred to in that study was by no means a general failure of these programs, but merely a failure of one lesson in one classroom. Specifically, the failure referred to by Smith and Anderson was that over half of the students in one fifth-grade SCIS class failed to realize that plants make their own food when exposed to sunlight after working through the relevant lessons. As I have argued previously (Lawson, 1988), this lack of understanding by most of these students was not a failure of the SCIS lessons (I have taught them successfully many times), but rather a failure of the teacher to allow the experiments to run to their completion.

Perhaps the teacher cut the experiments short because she was under some sort of pressure from the school principal to cover too many topics. If so, this is most unfortunate because rapid coverage of many topics results in superficial learning and misunderstanding, not the necessary deep processing witnessed in Ms. Copeland's class as just reported by Anderson. The implication is that policymakers need to see to it that schools adopt good inquiry-oriented programs such as SCIS or ESS (Elementary Science Study) and insist that teachers devote ample time to teaching them correctly. Investing money for inservice workshops to this end is a wise investment.

In a very real sense, I have just answered the central question of this paper: What do teachers need to know to teach science effectively? They need to know how to read and follow directions so they can do what the teachers' guides from these programs tell them to do. Regrettably not all grades are fortunate enough to have excellent inquiry-oriented programs to adopt and the question does, in fact, deserve an answer that not only tells teachers what science programs to teach, but also explains *why* they should teach those programs and explains how to design their own programs if necessary. Therefore, allow me to propose a second, more detailed, answer to the question.

A Second Answer

My second, more detailed answer to the question "What do teachers need to know to teach science effectively?" is contained in answers to the following six subquestions: (1) What is science? (2) Why teach science? (3) What is the nature of scientific knowledge? (4) How do people acquire scientific conceptual knowledge? (5) How do people develop scientific procedural knowledge? And (6) What teaching methods best

facilitate scientific knowledge acquisition? The primary purpose of my remaining remarks will be to provide answers to these questions and to argue that once these answers are understood, teachers will know what it is they need to know to teach science effectively.

1. What Is Science?

On the first day of each semester, I ask the new students in my Methods of Teaching Biology course to mark each of the following sentences TRUE or FALSE.

1. Science is a process of discovery of the nature of things via observation.
2. Truth is attainable via proof through repeated observation.
3. An hypothesis is an educated guess of what will be observed under certain conditions.
4. A conclusion is a statement of what was observed (#3).

This semester, 73 percent of the students marked sentence 1 TRUE. The other sentences, respectively, were marked TRUE by 43 percent, 70 percent, and 53 percent of the students. These percentages are typical of those from prior semesters and indicate that the majority of my students hold some serious misconceptions about the nature of science. This is alarming for two reasons. First, these students are seniors or graduates with majors in science. Second, many of them will become science teachers in the near future. Fortunately, by the end of the course most of the students appear to have acquired a better understanding of science and correctly mark all four sentences FALSE. That better understanding is reflected by such statements as

1. Science is a process of discovery of the nature of things via the creative generation of alternative hypotheses (via analogical reasoning) and their test. Observation may provoke questions and it provides data to allow the test of hypotheses but it does not lead to the discovery of the nature of things.

2. Ultimate proof and truth are not attainable using science. Rather, science merely allows us to present reasoned arguments and evidence for or against particular explanations for observed phenomena.

3. An hypothesis is a tentative explanation. A prediction is "an educated guess" of what is deduced to be observed under certain conditions provided the hypothesis is "true."

4. A conclusion is not a statement of what was observed, but is a statement of the relative "truth or falsity" of any particular hypothesis based upon the relationship between its predicted consequences and the actual results of some experimental and/or correlational test and the relationship between the hypothesis and the other conceptual systems that one holds.

Teachers need to understand the nature of the scientific process to teach science effectively.

2. Why Teach Science?

Misconception: The job of the teacher is to transmit scientific facts to students.
Alternative Conception: The job of the teacher is to foster creative and critical thinking skills.

In 1961 the Educational Policies Commission of the United States drafted a document entitled *The Central Purpose of American Education* (Educational Policies Commission, 1961). In that document the commission identified the *central* objective of education in America. That objective, in their words, is *freedom of the mind*. Their belief is that no person is born free, thus schools must foster skills required for this essential freedom. A free mind is one that can think and choose. According to the Educational Policies Commission, there exists rational powers, which if acquired constitute the free mind. These powers allow one to apply reason and the available evidence to ideas, attitudes, and actions, and to pursue better whatever goals he or she may have.

In 1966 the Educational Policies Commission, recognizing the key role which could be played by science education in development of the ability to think, published a second document entitled *Education and the Spirit of Science* (Educational Policies Commission, 1966). In that document they emphasized science not so much as a body of accumulated knowledge but as a way of thinking, a spirit of rational inquiry driven by a belief in its efficiency and by a restless curiosity to know and to understand. They also emphasized that this mode of thought, this spirit, relates to questions people usually ask and answer for reasons which they may think are totally nonscientific--religious, aesthetic, humanistic, literary. Thus the spirit of science infuses many forms of scholarship besides *science* itself.

Although it was recognized that no scientist may fully exemplify the spirit of science nor may their work be totally objective, it is clear that the following key values underlie science as an enterprise.

1. Longing to know and to understand.
2. Questioning of all things.
3. Search for data and their meaning.
4. Demand for verification.
5. Respect for logic.
6. Consideration of premises.
7. Consideration of consequences.

This list, by its nature, insists that students are not indoctrinated to think or act a certain way. Rather, it insists that they acquire the ability to make up their own minds; that is, to develop freedom of the mind, and to learn to make their own decisions based upon

reason and evidence. In this sense, the values of science are the most complete expression of one of the deepest human values--the belief in human dignity. Consequently these values are part and parcel of any true science but, more basically, of rational thought and they apply not only in science, but in every area of one's life. What then is being advocated by the Educational Policies Commission is science education not only for the production of more scientists, but for the development of persons whose approach to life is that of a person who thinks creatively and critically (cf., Resnick, 1987). Thus, the central goal of science teaching at virtually any level is to foster this type of thought. To teach science effectively, teachers need to know this.

3. What Is the Nature of Scientific Knowledge?

Cognitive science distinguishes two fundamental types of knowledge--declarative and procedural. The distinction is essentially between "knowing that" (e.g., I know that animals inhale oxygen and expel carbon dioxide) and "knowing how" (I know how to perform a controlled experiment). Anderson (1980) defines declarative knowledge and procedural knowledge in the following way: "Declarative knowledge comprises the facts that we know; procedural knowledge comprises the skills we know how to perform" (p. 222).

The Nature of Declarative Knowledge

The declarative aspects of science subject matter are composed of a series of concepts of various degrees of complexity, abstractness, and importance. These are generally seen as the primary units of instruction. A concept has been formed whenever two or more distinguishable objects, events or situations have been grouped or classified together and set apart from other objects, events or situations on the basis of some common feature, form or properties of both (after Bourne, 1966, p. 2). A concept can be considered to be a unit of thought which exists in a person's mind.

Concepts do not stand alone. Rather, they are integrated into meaningful systems often with hierarchical structure of subordinate and superordinate concepts (cf., Ausubel, 1963; Bruner, 1963; Gagné, 1970; Lawson, 1958; Novak, Gowin, and Johansen, 1983). These systems of interrelated concepts are called "conceptual systems." An example of such a conceptual system is the ecosystem from ecological theory. This conceptual system consists of concepts such as trees, sunlight, frogs, producers, consumers, food webs, community, environmental factors, and ecosystem itself. The hierarchy of concepts with the basic units of trees, frogs, sunlight and so on at the bottom and ecosystem at the top form the conceptual system known as ecosystem. The concept ecosystem is all inclusive. All of the previously mentioned concepts are mentally integrated under the term "ecosystem." Figure 1 shows a number of the subordinate concepts which must be interrelated to form the inclusive concept of ecosystem.

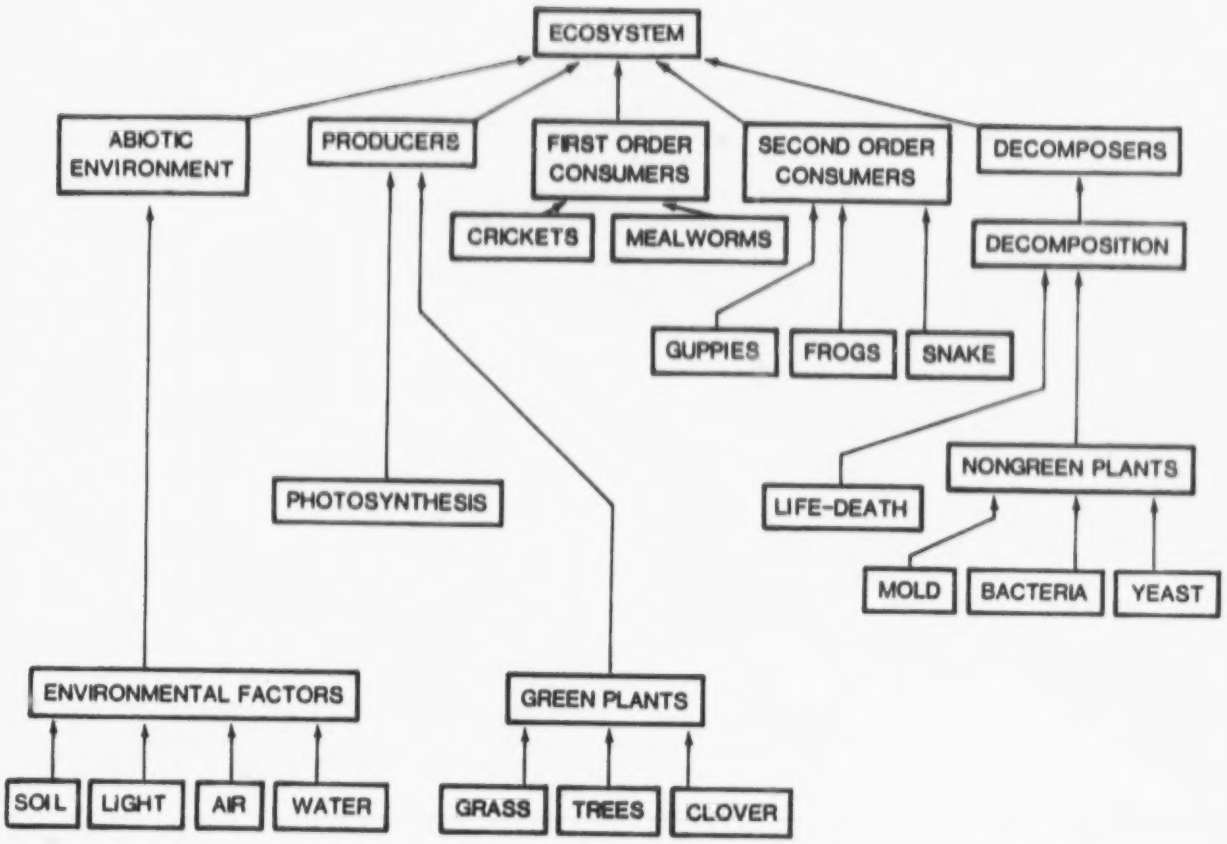

Figure 1. A number of interrelated concepts which are subordinate to the inclusive concept of "ecosystem." Interrelationships among subordinate concepts are complex, yet generally hierarchical.

As previously defined, a concept refers to some pattern (regularity) to which a term or terms have been applied. Terms fall into different types according to the different sources of meaning. There are, I believe, at least three major ways in which meaning can be derived. Hence, there are three major types of concepts. One can have concepts about immediately sensed input such as the color green, hot-cold, sharp-dull, internal states such as hunger, thirst, tiredness and so on. The complete meaning of such terms is derived immediately from the internal or external environment. The term *blue*, for example, derives its meaning from something that is immediately apprehended. Thus, concepts *by apprehension* are the first major type of concept (Northrop, 1947).

The second type of concept is called *descriptive*. Objects such as tables, chairs, other persons, the room; events such as running, resting, playing, eating; situations such as on top of, before, under, next to, and so on are not immediately apprehended. The meaning of such terms must come through direct interaction with the "world out there." Babies are not born with the ability to perceive objects in their environment as they perceive them later on (Piaget, 1952). As Northrop (1947) said, "perceptual objects are not immediately apprehended factors; they are postulates of common sense so thoroughly and frequently and unconsciously verified through their deductive consequences that only the critical realize them to be postulated rather than immediately apprehended" (p. 93). In other words, even tables and chairs are mentally constructed entities.

Descriptive concepts also refer to perceived relations of objects and events. Taller, heavier, wider, older, on top of, before, under, are all terms that derive meaning from a direct comparison of objects or events. To understand the meaning of such terms, the individual must mentally construct order from environmental encounters. However, his mental constructions can always be compared with and thus verified or falsified by direct experience. Such descriptive concepts allow us to order and describe direct experience.

The third type of concept is one that is also produced by postulation. However, it differs from descriptive concepts in that its defining attributes are not perceptible. The primary use of these concepts is to function as explanations for events that need causes but for which no causal agent can be directly perceived. Fairies, poltergeists and ghosts fall into this category. Common examples from science are genes, atoms, molecules, electrons, natural selection, and so forth. These are called *theoretical concepts*. Because theoretical concepts are imagined and function to explain the otherwise unexplainable, they can be given whatever properties or qualities necessary in terms of the theory of which they are a part. That is, they derive their meaning in terms of the postulates of specific theories (Lawson, 1958; Lewis, 1980, 1988; Northrop, 1947; Suppes, 1968).

Basically, conceptual systems are of two types, descriptive or theoretical, depending on the nature of the concepts which comprise the system. A descriptive conceptual system is composed of concepts by apprehension and descriptive concepts only. A theoretical

system is composed of concepts by apprehension, descriptive concepts, and theoretical concepts. Examples of descriptive conceptual systems are human anatomy, early Greek cosmology, taxonomies, and games such as chess, football and baseball. Each of these systems consists of concepts about perceivable objects and the interactions of these objects.

Theoretical conceptual systems are exemplified by atomic-molecular theory, Mendelian genetics, Darwin's theory of evolution through natural selection and so on. In atomic-molecular theory, the atoms and molecules were imagined to exist and to have certain properties and behaviors, none of which could be observed. However, by assigning certain properties to atoms that included combining with each other to form molecules, observable chemical changes could be explained. In the same manner, Mendel imagined genes to exist that occurred in pairs, separated at the time of gamete formation, combined when egg and sperm united, and determined the course of development of the embryo. By assuming the gene existed and had certain properties and behavior, Mendel could explain the observable results from crosses of plants and animals.

Each conceptual system is composed of a finite set of basic postulates that taken together define the system and certain basic concepts of that system. For example, the basic postulates of classic Mendelian genetics are as follows:

1. Inherited traits are determined by particles called genes.
2. Genes are passed from parent to offspring in the gametes.
3. An individual has at least one pair of genes for each trait in each cell except the gametes.
4. Sometimes one gene of a pair masks the expression of the second gene (dominance).
5. During gamete formation, paired genes separate. A gamete receives one gene of each pair.
6. There is an equal probability that a gamete will receive either one of the genes of a pair.
7. When considering two pairs of genes, the genes of each pair assort independently to the gametes.
8. Gene pairs separated during gamete formation recombine randomly during fertilization.

These postulates, when taken together, constitute the essence of a theoretical conceptual system (i.e., a theory) used to explain how traits are passed from parent to offspring. Concepts such as gene, dominance, recessive characteristics, independent assortment, and segregation derive their meaning from postulates of the system. When the postulates of a theory such as Mendel's theory become widely accepted, the theory is referred to as an "embedded" theory and its postulates take on the status of "facts." The postulates of many important scientific theories have been identified by Lewis (1980, 1987, 1988).

The Nature of Procedural Knowledge

The procedures one uses to generate declarative knowledge are collectively known as procedural knowledge. Various reasoning patterns (cognitive strategies) such as combinatorial reasoning (the generation of combinations of alternative hypotheses) the control of variables (experimenting in a way which varies only one independent variable) and correlational reasoning (comparing ratios of confirming to disconfirming events) are components of procedural knowledge.

Because of the central importance of procedural knowledge in science and in creative and critical thinking in general, psychologists and educators alike have attempted to identify its components with as much precision as possible. One of the early attempts to do so contained eight central skills and several subskills (Burmester, 1952). A modified list of those skills appears below grouped into seven categories intended to be easily relatable to the general pattern of scientific thinking (depicted in Figure 4). The seven categories are as follows:

1. Skill in accurately describing nature.
2. Skill in sensing and stating causal questions about nature.
3. Skill in recognizing, generating and stating alternative hypotheses and theories.
4. Skill in generating logical predictions.
5. Skill in planning and conducting controlled experiments to test hypotheses.
6. Skill in collecting, organizing and analyzing relevant experimental and correlational data.
7. Skill in drawing and applying reasonable conclusions.

Some of the above skills are creative, while others are critical. Still others involve both creative and critical aspects of scientific thinking. We are defining a skill as the ability to do something well. Skilled performance includes knowing what to do, when to do it, and how to do it. In other words, being skilled at something involves knowing a set of procedures, knowing when to apply those procedures, and being proficient at executing those procedures. The seven general skills listed above can be further delimited into the subskills listed in Table 1.

These skills function in concert in the mind of the creative and critical thinker as he or she learns about the world. The skills are, in essence, learning tools essential for success and even for survival. Hence, if you help students improve their use of these creative and critical thinking skills you have helped them become more intelligent and helped them "learn how to learn." To teach science effectively, teachers need to understand the distinction between declarative and procedural knowledge and they need to have acquired knowledge of many scientific theories and have developed skill in using scientific procedural knowledge.

Table 1

General Creative and Critical Thinking Skills

1.00 Skill in accurately describing nature.
- 1.10 Skill in describing objects in terms of observable characteristics.
- 1.20 Skill in seriating objects in terms of observable characteristics.
- 1.30 Skill in classifying objects in terms of observable characteristics.
- 1.40 Skill in describing, seriating, classifying, and measuring objects in terms of variables such as amount, length, area, weight, volume, and density.
- 1.50 Skill in identifying variable and constant characteristics of groups of objects.
  - 1.51 Skill in identifying continuous and discontinuous variable characteristics and naming specific values of those characteristics.
  - 1.52 Skill in measuring, recording and graphing the frequency of occurrence of certain values of characteristics in a sample of objects.
  - 1.53 Skill in determining the average, median, and modal values of the frequency distribution in 1.52 above.
- 1.60 Skill in recognizing the difference between a sample and a population and identifying ways of obtaining a random (unbiased) sample.
  - 1.61 Skill in making predictions concerning the probability of occurrence of specific population characteristics based upon the frequency of occurrence of those characteristics in a random sample.

2.00 Skill in sensing and stating causal questions about nature.
- 2.10 Skill in recognizing a causal question from observation of nature or in the context of a paragraph or article.
- 2.20 Skill in distinguishing between an observation and a question.
- 2.30 Skill in recognizing a question even when it is stated in expository form rather than in interrogatory form.
- 2.40 Skill in distinguishing a question from a possible answer to a question (hypothesis) even when the hypothesis is presented in interrogatory form.
- 2.50 Skill in distinguishing between descriptive and causal questions.

3.00 Skill in recognizing, generating and stating alternative hypotheses (causal explanations) and theories.
- 3.10 Skill in distinguishing an hypothesis from a question.
- 3.20 Skill in differentiating between a statement that describes an observation or generalizes from the observation and a statement which is an hypothesis (causal explanation) for the observation.
- 3.30 Skill in recognizing the tentativeness of an hypothesis or theory.
- 3.40 Skill in distinguishing between a tentative explanation for a phenomenon (hypothesis) and a term used merely to label the phenomenon.
- 3.50 Skill in systematically generating all possible combinations of generated hypotheses.

4.00 Skill in generating and stating logical predictions based upon the assumed truth of hypotheses and imagined experimental conditions.
- 4.10 Skill in differentiating between hypotheses and predictions.

5.00 Skill in planning and conducting controlled experiments to test alternative hypotheses.
- 5.10 Skill in selecting reasonable alternative hypotheses to test.
- 5.20 Skill in differentiating between an uncontrolled observation and an experiment involving controls.
- 5.30 Skill in recognizing that only one independent factor in an experiment should be variable.
  - 5.31 Skill in recognizing the independent variable factor and the dependent variable factor(s).
  - 5.32 Skill in recognizing the factors being held constant in the partial controls.

5.40 Skill in recognizing experimental and technical problems inherent in experimental designs.

5.50 Skill in criticizing faulty experiments when

- 5.51 The experimental design was such that it could not yield an answer to the question.
- 5.52 The experiment was not designed to test the specific hypotheses stated.
- 5.53 The method of collecting the data was unreliable.
- 5.54 The data were not accurate.
- 5.55 The data were insufficient in number.
- 5.56 Proper controls were not included.

6.00 Skill in collecting, organizing, and analyzing relevant experimental and correlational data.

- 6.10 Skill in recognizing existence of errors in measurement.
- 6.20 Skill in recognizing when the precision of measurement given is warranted by the nature of the question.
- 6.30 Skill in organizing and analyzing data.
  - 6.31 Skill in constructing tables and frequency graphs.
  - 6.32 Skill in measuring, recording, and graphing the values of two variables on a single graph.
  - 6.33 Skill in constructing a contingency table of discontinuous variables.
- 6.40 Skill in seeing elements in common to several items of data.
- 6.50 Skill in recognizing prevailing tendencies and trends in data and to extrapolate and interpolate.
- 6.60 Skill in applying quantitative notions of probability, proportion, percent, and correlation to natural phenomena and recognize when variables are related additively or multiplicatively setting up simple quantitative equations describing these relationships.
  - 6.61 Skill in recognizing direct, inverse, or no relationship between variables.
  - 6.62 Skill in recognizing that when two things vary together, the relationship may be coincidental, not causal.
  - 6.63 Skill in recognizing additional evidence needed to establish cause and effect (see 6.62 above).

7.00 Skill in drawing and applying reasonable conclusions.

- 7.10 Skill in evaluating relevancy of data and draw conclusions through a comparison of actual results with predicted results.
  - 7.11 Skill in differentiating between direct and indirect evidence.
  - 7.12 Skill in recognizing data which are unrelated to the hypotheses.
  - 7.13 Skill in recognizing data which support an hypothesis.
  - 7.14 Skill in recognizing data which do not support an hypothesis.
  - 7.15 Skill in combining both supportive and contradicting evidence from a variety of sources to weigh the likely truth or falsity of hypotheses.
  - 7.16 Skill in postponing judgement if no evidence or insufficient evidence exists.
  - 7.17 Skill in recognizing the tentativeness inherent in all scientific conclusions.
- 7.20 Skill in applying conclusions to new situations.
  - 7.21 Skill in refraining from applying conclusions to new situations which are not closely analogous to the experimental situation.
  - 7.22 Skill in being aware of the tentativeness of conclusions about new situations even when there is a close parallel between the two situations.
  - 7.23 Skill in recognizing the assumptions which must be made in applying a conclusion to a new situation.

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4. How Do People Acquire Scientific Conceptual Knowledge?

The Constructive Process

To acquire a sense of how the formation of descriptive concepts takes place, consider the drawings in Figure 2. The first row of Figure 2 contains five "creatures" called Mellinarks (Elementary Science Study, 1974). None of the creatures in the second row are Mellinarks. From this information try to decide which of the creatures in the third row are Mellinarks.

The problem of deciding which of the creatures in row three is/are Mellinarks is an example of descriptive concept formation. If you correctly identified the first, second and sixth figures as Mellinarks you have formed a "concept" for the term *Mellinark*. How did you do it? Outdated theories of abstraction (Locke, 1690/1924; Hume, 1739/1896) would claim that you "induced" a set of specific characteristics and generalized it to other instances. Modern theories, on the other hand, emphasize the importance of hypothesis generation and the predictive nature of concept formation (e.g., Bolton, 1977; Holland, Holyoak, Nisbett, and Thagard, 1986; Mayer, 1983).

Let us consider a solution employing the more modern notion of hypothesis generation and testing. A glance at row one reveals several features of the Mellinarks. They have tails. They contain one large dot and several smaller dots. They have an enclosed cell-like membrane that may have curved or straight sides. If we assume that features such as these are crucial, then which ones? The nature of the membrane (curved or straight) can be eliminated immediately as both membrane types exist in row one. The importance of the other three features can be tested easily starting with some hypotheses as follows. Mellinarks consist of creatures with

1. One large dot only
2. Several small dots only
3. One tail only
4. One large dot & several small dots
5. One large dot & one tail
6. Several small dots & one tail
7. One large dot & several small dots & one tail

Hypothesis 1 would lead one to predict that all the creatures of row one and none of the creatures in row two would contain one large dot. Since this is not the case, the prediction is disconfirmed and the hypothesis that Mellinarks are creatures distinguished solely by the presence of one large dot is also disconfirmed. The same pattern of hypothetico-deductive reasoning leads one to disconfirm hypotheses 2 through 6 as well, leaving hypothesis 7, that Mellinarks are defined by the presence of all three features, as "correct." Thus only the first, second, and sixth creatures in row three are Mellinarks. Concept formation, seen in this light, is not viewed as a purely abstractive process but rests

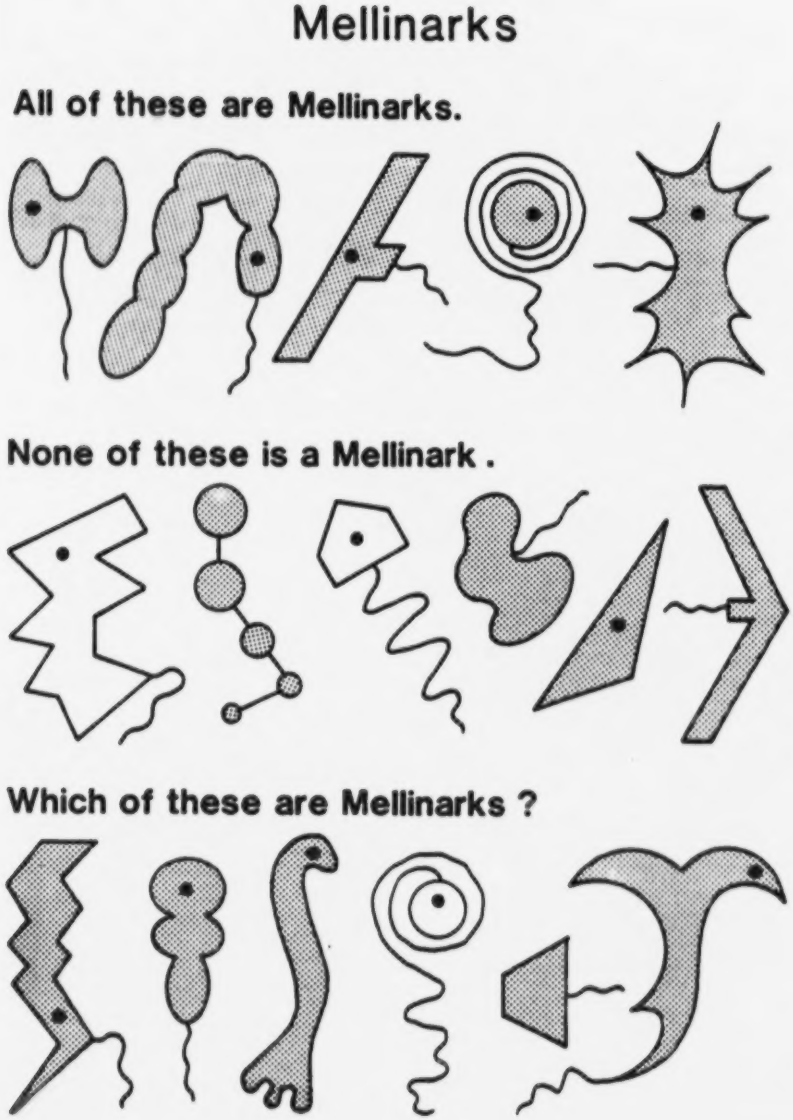


Figure 2. Imaginary creatures called Mellinarks (from Elementary Science Study, 1974).

on the ability to generate and test hypotheses. In this sense one's conceptual knowledge (an aspect of declarative knowledge) depends upon one's procedural knowledge. As one gains skill in using these hypothetico-deductive procedures, concept formation becomes easier. More will be said about this later when we discuss the development of procedural knowledge. In the case of the Mellinarks, the concept formed is a descriptive one as its defining attributes are directly perceptible.

The Role of Chunking in Higher Order Concept Formation

The human mind at any one moment is able to integrate mentally or process only a limited amount of information. Miller (1956) introduced the term "chunk" to refer to the discrete units of information that could be consciously held in working memory and transformed or integrated. He cited considerable evidence to suggest that the maximum number of these discrete chunks was approximately seven.

Clearly, however, we all form concepts that contain far more information than seven units. The term ecosystem, as mentioned, subsumes a far greater number of discrete units or chunks than seven. Further, the term "ecosystem" itself is a concept, thus it probably occupies but one chunk in conscious memory. This implies that a mental process must occur in which previously unrelated parts--that is, chunks of information (a maximum of about seven chunks)--are assembled by the mind into one higher order chunk or unit of thought. This implied process is known as chunking (Simon, 1974).

The result of higher order concept formation (chunking) is extremely important. It reduces the load on mental capacity and simultaneously opens up additional mental capacity that can then be occupied by additional concepts. This in turn allows one to form still more complex and inclusive concepts (i.e., concepts which subsume greater numbers of subordinate concepts). To turn back to our initial example, once we all know what a Mellinark is we no longer have to refer to them as "creatures within an enclosed membrane that may be curved or straight, one large dot and several smaller dots inside and one tail." Use of the term Mellinark to subsume all of this information greatly facilitates thinking *and* communication when both parties have acquired the concept. See Ausubel (1963) and Ausubel, Novak, and Hanesian (1968) for details of the subsumption process.

How Are Theoretical Concepts Formed?

The preceding discussion of descriptive concept formation leaves two important issues unresolved. How does concept formation take place when the defining attributes are not directly perceptible, that is when the concept in question is a theoretical one? And what takes place when the theoretical concept to be acquired contradicts a previously acquired concept? Again let us consider these issues through the use of an example. The example is that of Charles Darwin as he changed his view from that of a creationist to that of an evolutionist. Further he invented a satisfactory theory of evolution through natural selection.

Note that the concepts of creationism, evolution, and natural selection are all theoretical, according to our previous definition.

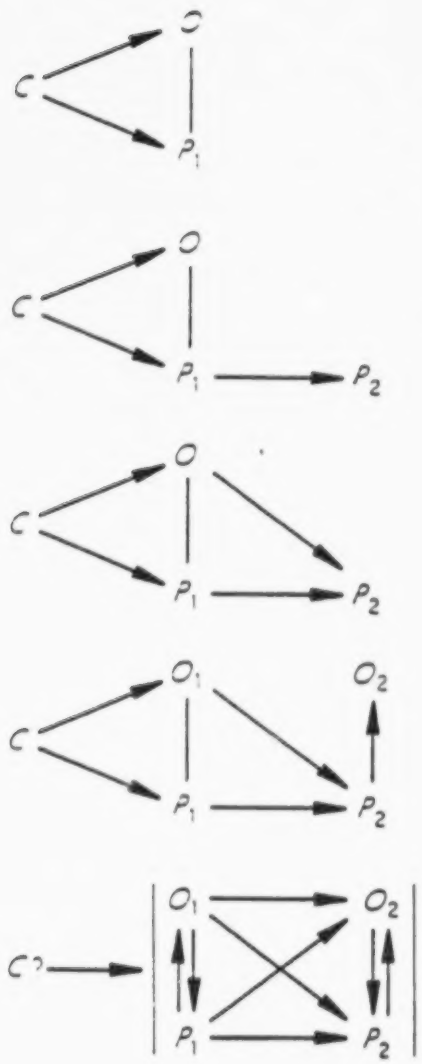
Let us consider the process of conceptual change first. How are inappropriate theoretical concepts modified or discarded in favor of more appropriate theoretical concepts? This is a difficult question to answer, primarily because the process takes place inside people's heads away from the observer and often at a subconscious level. Thus it is not only hidden from the researcher, but often hidden from the subject as well.

Conceptual change. To get a handle on this problem, Gruber and Barrett (1974) analyzed Darwin's thinking during the period 1831 to 1838 when he underwent a conceptual change from a creationist theory of the world (a misconception in today's scientific thinking) to that of an evolutionist (a currently valid scientific conception). Fortunately for Gruber and Barrett and for us, Darwin left a record of much of his thinking during this period in copious diaries. Figure 3 highlights the major changes in his theoretical conceptual system during this time.

Darwin's theory in 1831 has been described by Gruber and Barrett (1974) as one in which the creator made an organic world (O) and a physical world (P). In this view, theorganic world was perfectly adapted to the physical world (see a of Figure 3). This view of the world served Darwin well and his thoughts and behavior were consistent with this view. Although Charles Darwin was most certainly a creationist in 1831 he was well aware of evolutionary views. Nevertheless, Charles Darwin on that day in 1831, when he boarded the HMS *Beagle* as the ship's naturalist, was seeking an adventure--not seeking a theory of evolution.

During the first two years of the voyage on the *Beagle*, Darwin read some persuasive ideas about the modification of the physical environment through time by Charles Lyell (1835) in his two-volume work entitled *Principles of Geology*. At each new place Darwin visited, he found examples and important extensions of Lyell's ideas. Darwin was becoming increasingly convinced that the physical world was not static--it changed through time. This new conception of the physical world stood in opposition to his earlier beliefs and it created a serious contradiction. If the organic world and the physical world are perfectly adapted, and the physical world changes, then the organic world must also change. This, of course, is the logical extension of the argument. Its conclusion, however, was the opposite of Darwin's original theory that organisms did not evolve.

This contradiction of views put Darwin into what Piaget has called a state of mental *disequilibrium* because Darwin did not immediately accept the logic of this situation and conclude that organisms must also change. In fact, it was not until 1837, after his return to England, that he was converted to the idea of evolution of species (Green, 1958). It seems unlikely that it would require this amount of time for Darwin to assimilate the logic of the situation, but the fact of the matter is that in the 2,000 pages of geological and biological notes made during the voyage, there is very little discussion of the evolution of organisms. What little there is opposes the idea.



a. 1832 and before: The creator (C) made an organic world (O) and a physical world (P): O was perfectly adapted to P. Mental equilibrium exists.

b. 1832-1834: The physical world undergoes continuous change, governed by natural forces as summarized in Lyell's *Principles of Geology*. A logical contradiction is implied which induces a state of disequilibrium.

c. 1835: Activities of organisms contribute to changes in the physical world (e.g., coral reefs). Disequilibrium persists.

d. 1836-1837: Changes in the physical world imply changes in the organic world if adaptation is to be maintained; the direct action of the physical environment "induces" organic adaptations. Equilibrium is partially restored.

e. 1838 and after: The physical and organic worlds continuously interact and induce reciprocal changes to maintain adaptations. The role of the creator is unclear. He may have set the system into existence yet stands outside. Mental equilibrium is restored at a higher more complex plane.

Figure 3. Charles Darwin's changing world view from 1832 to 1838 as an example of mental equilibration (after Gruber and Barrett 1974).

Precisely how and why Darwin changed his view is, of course, not known. Figure 3, however, appears to be a fairly accurate summary of his changing world view. Smith and Millman (1987) have also carefully examined Darwin's notebook (particularly the B notebook) and have characterized Darwin's mind as in a state of "exploratory thinking" meaning that, rather than accepting any particular theory, Darwin was considering various views (alternative hypotheses) to explain the situation as he saw it. If we assume that the weight of accumulating evidence forced a rejection of special creation (e.g., physical change, intermediate "forms" of organisms, untold diversity of species = more than could reasonably be held on Noah's ark), then this exploratory thinking was aimed primarily at explaining evolution. Figure 3e thus represents the partial restoration of mental equilibrium as it eliminates the logical contradiction implied in Figure 3b.

Piaget refers to the process of moving from a mental state of equilibrium to disequilibrium and back to equilibrium as *equilibration*. Therefore, an initial answer to the question how does conceptual change occur is through the process of equilibration. The necessary conditions for conceptual equilibration to take place appear to be (a) data which are inconsistent with prior ways of thinking, (b) the presence of alternative conception/hypotheses (the hypothesis of evolution), and (c) sufficient time, motivation and thinking, skills to compare the alternative hypotheses and their predicted consequences with the evidence (cf., Anderson and Smith, 1987; Hewson and Hewson, 1984; Lawson & Thompson, 1988; Posner, Strike, Hewson, and Gertzog, 1982).

The use of analogy. Once Darwin had accepted the alternative hypothesis that organisms evolve, the question of "How?" immediately arose. Of course his answer was through a process called natural selection. Thus, natural selection represents a theoretical concept employed by Darwin. Further, unlike the example of our formation of the descriptive concept of Mellinarks, the defining attributes of the concept of natural selection are not visible. By what intellectual process did Darwin come to use the concept of natural selection? How, in general, are theoretical concepts formed?

According to the record (e.g., Green, 1958; Gruber and Barrett, 1974; Smith and Millman, 1987), Darwin's search for a theory to explain the evolution of organisms involved a number of initially unsuccessful trials and a good deal of groping until September of 1838 when a key event occurred. Darwin read Thomas Malthus's (1798) *Essay on Population*. Darwin wrote, "I came to the conclusion that selection was the principle of change from the study of domesticated productions; and then reading Malthus, I saw at once how to apply this principle" (Green, 1958, pps. 257-258). Darwin saw in Malthus's writing a key idea that he could *borrow* and use to explain evolution. That key idea was that *artificial* selection of domesticated plants and animals was *analogous* to what presumably occurs in nature and could account for a change or evolution of species. As Gruber and Barrett (1974, pps. 118-119) point out, Darwin had read Malthus before but it was not until this reading that he became conscious of the import of the artificial selection process. But once

it had been assimilated, Darwin turned to the task of marshalling the evidence favoring his theory of descent with modification.

The example of Darwin's use of artificial selection suggests that analogy plays a central role in theoretical concept formation. The "idea" or pattern that allowed Darwin to make sense of his data was analogous to the pattern inherent in the process of artificial selection. Hanson refers to this process of the borrowing of old ideas and applying them in new situation as "abduction" (Hanson, 1947). Others have referred to the process as analogical reasoning (Karplus, 1979; Lawson & Lawson, 1979) or analogical transfer (Holland, Holyoak, Nisbett, and Thagard, 1986).

Thus, the answer to the question of how theoretical concepts are formed is by applying a previously acquired pattern from the world of observable objects and events to explain unobservable events. The scientist must discover the analogy for him or herself while the student *in the classroom* can be assisted by having the teacher point out the relevant analogy.

The General Pattern of Concept Formation and Conceptual Change

Upon reflection we can identify a general pattern which exists in both processes of concept formation and conceptual change. The pattern exists in both because what we are considering in concept formation and change are not really two different processes but two ends of the same continuum. As Piaget reminds us, every act of assimilation to a cognitive structure is accompanied by some accommodation of that structure. No two experiences are ever identical, therefore pure assimilation is not possible. Likewise, pure accommodation presumably does not take place because that would imply that a cognitive reorganization has taken place without any input from the environment. Thus, at the concept formation end of the continuum we have the dominance of assimilation over accommodation and at the conceptual change end of the continuum we have a dominance of accommodation over assimilation.

The general pattern is shown in Figure 4. Box A represents the question which was been prompted due to some experience (e.g., what is a Mellinark? How did the diversity of species arise?) Box B represents alternative hypotheses which have arisen either by the selection of perceptible features of the problem situations (induction) or via analogical reasoning (abduction) from either one's own memory or that of others (e.g., in books). The use of analogical reasoning is an important component of what is often referred to as creative thinking. Importantly the subconscious mind plays an important role in the generation of novel ideas.

To test alternative hypotheses some experimental and/or correlational situation must be imagined which allows the deduction of the ideas' logical consequences (Box C). The logical consequences (predictions) are then compared with the actual results of the test which are represented by Box D. If the predicted results and the actual results are essentially the same then support for the hypothesis has been obtained. If not, the

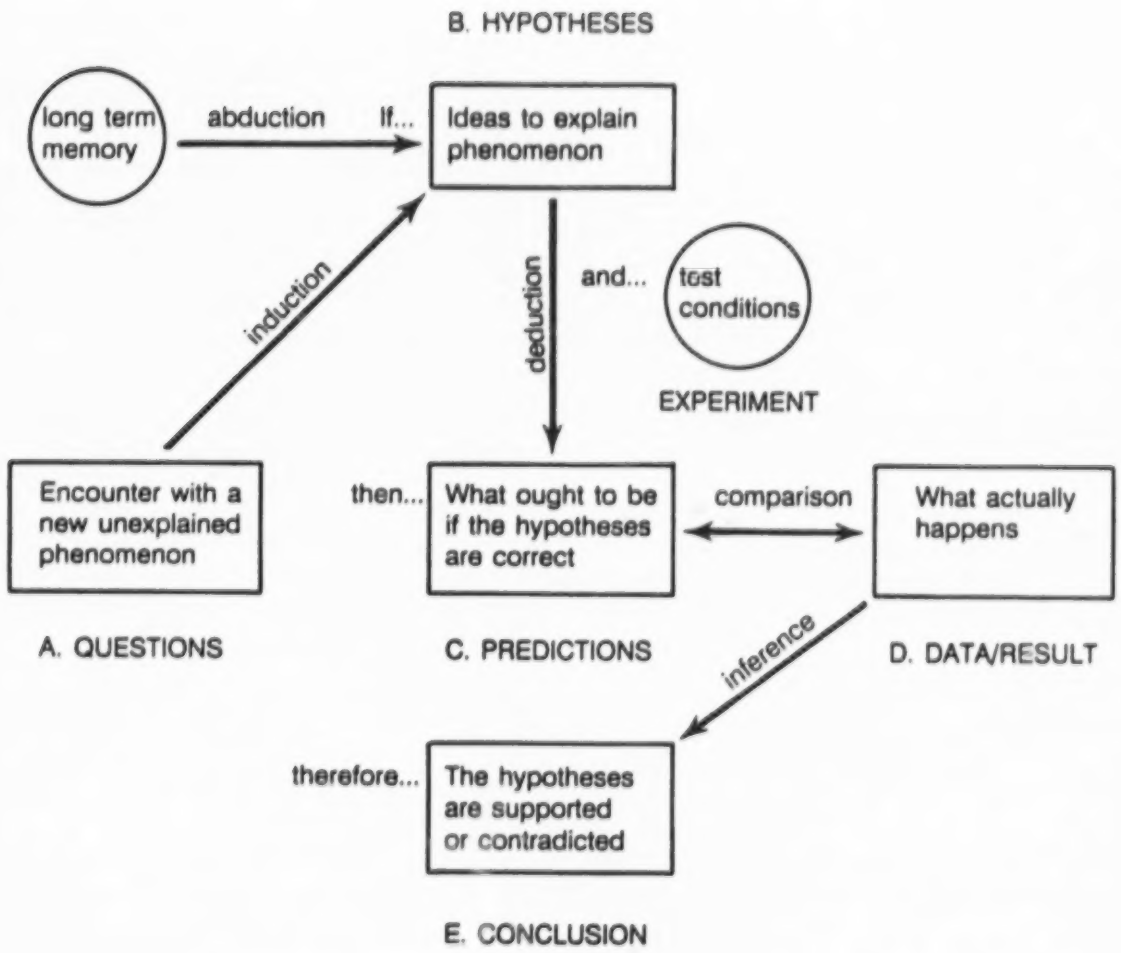


Figure 4. The basic pattern of hypothetico-deductive thinking.

hypothesis has been weakened and others should be generated and tested until a reasonable agreement is obtained. Note how the words if . . . and . . . then and therefore tie the elements of the hypothetico-deductive process together into a reasonable argument for or against any particular hypothesis or set of alternatives.

The acquisition of declarative knowledge is very much a constructive process which makes either implicit or explicit use of the procedural knowledge. Of course students can memorize, in a rote fashion, aspects of declarative knowledge but such learning by rote will not assist in the improvement of the procedural knowledge. To teach science effectively teachers need to know how to teach in such a way that students participate in the constructive process because doing so improves meaningfulness and retention of the declarative knowledge and increases consciousness and generalizability of the procedural knowledge.

5. How Do People Develop Scientific Procedural Knowledge?

A great deal has been written about the development of procedural/operative knowledge within the Piagetian tradition (e.g., Collette and Chiappetta, 1986; Collea, Fuller, Karplus, Paldy, and Renner, 1975; Inhelder and Piaget, 1958; Karplus et al., 1977). Piaget's stages of sensory-motor, preoperational, concrete operations, and formal operations are well known. Little argument exists over the validity of the notion of levels or phases in the development of procedural knowledge but considerable controversy exists regarding the details.

In Piaget's theory the child at birth is in a stage called sensory-motor. During this stage, which lasts for about 18 months, the child acquires such practical knowledge as the fact that objects continue to exist even when they are out of view (object permanence). The name of the second stage describes the characteristics of the child: *preoperational*--the stage of intellectual development before mental operations appear. In this stage, which persists until around seven years of age, the child exhibits extreme egocentricism, centers his attention only upon particular aspects of given objects, events, or situations, and does not demonstrate conservation reasoning. In other words, the child's thinking is very rigid. The major achievement during this stage is the acquisition of language.

At about seven years of age the thinking processes of children begin to "thaw out"; they show less rigidity. This stage, called *concrete operational*, is marked by the development of operations. Concrete operations are defined as mentally internalized and reversible systems of thought based on manipulations of classes, relations, and quantities of objects. The child can now perform what Piaget calls mental experiments; he can assimilate data from a concrete experience and arrange and rearrange them in his head. In other words, the concrete operational child has a much greater mobility of thought than when he was younger. As Piaget explains this stage, "The operations involved . . . are called 'concrete' because they relate directly to objects and not yet to verbally stated hypotheses" (Piaget and

Inhelder 1969, p. 100). In other words, the mental operations performed at this stage are "object bound"--operations are tied to objects.

The potential for the development of what Piaget calls *formal operational* thought presumably develops between 11 and 15 years of age. For Piaget, the stage of formal operations constitutes the highest level in the development of mental structures. A person who has entered that stage of formal thought "is an individual who thinks beyond the present and forms theories about everything, delighting especially in considerations of that which is not" (Piaget, 1966, p. 148). Piaget chose the name *formal operational* for his highest stage of thought because of his belief that thinking patterns are isomorphic with rules of formal propositional logic (cf., Piaget, 1957). This position is perhaps the most problematic in Piaget's theory. A long line of research indicates clearly that, although advances in reasoning performance do occur during adolescence, no one, even professional logicians, reason with logical rules divorced from the subject matter (Griggs, 1983; Lehman, Lempert, and Nisbett, 1988; Nisbett, Fong, Lehman, and Cheng, 1987; Wason and Johnson-Laird, 1972).

Reflectivity and the Internalization of Patterns of Argumentation

If the acquisition of formal rules of logic do not differentiate the thinking of the child from that of the adolescent, then what does? Lawson, Lawson, and Lawson (1984) hypothesized that the important shift is one towards greater reflectivity due to the adolescent's ability to ask questions, not of others, but of oneself and to reflect on the correctness or incorrectness of answers to those questions in a hypothetico-deductive manner. This internalized hypothetico-deductive question asking and answering behavior involves the acquisition of linguistic skills associated with hypothesis testing and leads ultimately to the development of hypothesis-testing schemes and patterns of argumentation. In other words, prior to adolescence the children raise questions, generate answers, yet have no systematic means of asking themselves if their answers are correct or not. They must rely on others for this so when left on their own they simply generate ideas and for the most part use them for better or for worse. Without such a reflective ability children confronted with complex tasks simply choose the most obvious solution that pops into their heads and conclude that it is correct without consideration of arguments in its favor or disfavor.

Kuhn, Amsel, and O'Loughlin (1988) reached a similar conclusion regarding the differences between child-like and adult-like thinking. They identified three key abilities that are acquired by some adults. First is the ability to think *about* a theory rather than thinking only with a theory. In other words, the reflective adult is able to consider alternative theories, and ask which is the most acceptable. On the other hand, the intuitive thinker does not consider the relative merits and demerits of alternative theories (hypotheses), he/she merely has a "theory" and behaves as though it was true. Chamberlain (1897/1965) referred to these are ruling theories.

Second is the ability to consider the evidence to be evaluated as distinct from the theories themselves. For the child, evidence and theory are indistinguishable. In our

experience perhaps the most difficult distinction to be made in the classroom is that between the words *hypothesis*, *prediction*, and *evidence* (Lawson, Lawson, and Lawson, 1984). Presumably this is the case because the words are essentially meaningless if one has never before tried to decide between two or more alternative explanations, thus has never before considered the role played by predictions and evidence. Third is the ability to set aside one's own acceptance (or rejection) of a theory in order to objectively evaluate it in light of its predictions and the evidence.

Lawson, Lawson, and Lawson (1984) hypothesized that the ability to reflect on the correctness of one's theories arises as a consequence of the internalization of patterns of external argumentation which occurs with others when alternative theories are proposed. This hypothesis appears to be in essential agreement with Piaget's earlier thinking. Piaget (1928) advanced the hypothesis that the development of advanced reasoning occurred as a consequence of "the shock of our thoughts coming into contact with others, which produces doubt and the desire to prove" (p. 204). Piaget went on to state:

> The social need to share the thought of others and to communicate our own with success is at the root of our need for verification. Proof is the outcome of argument. . . . Argument is therefore, the backbone of verification. Logical reasoning is an argument which we have with ourselves, and which produces internally the features of a real argument. (p. 204)

In other words, the growing awareness of and ability to use the pattern of hypothetico-deductive thought during adolescence (defined as the ability to ask questions of oneself, generate tentative answers, deduce predictions based upon those answers, and then sort through the available evidence to verify or reject those tentative answers--all inside one's own head), occurs as a consequence of attempting to engage in arguments of the same sort with other persons and listening to arguments of others in which alternative propositions (theories) are put forward and accepted or rejected as the basis of evidence and reason as opposed to authority or emotion.

This position also seems consistent with that of Vygotsky (1962) who views speech as social in origin and only with time does it come to have self-directive properties that eventually result in internalized verbalized thought. This position is also similar to that of Luria. According to Luria (1961) the progressive differentiation of language to regulate behavior occurs in four steps. First, the child learns the meaning of words; second, language can serve to activate behavior but not limit it; third, language can control behavior through activation or inhibition via communication from an external source; and fourth, the internalization of language can serve a self-regulating function through instructions to oneself.

Even Piaget (1976) proposed a similar three-level theory of procedural knowledge development. The first level (sensory-motor) is one in which language plays little or no role as it has yet to be acquired. The child learns primarily through sensory-motor activity

and knowledge is that of action. The second level is characterized by the acquisition of language. The child is able to respond to spoken language and acquire knowledge transmitted from adults who speak the same language. To learn, the child is able to raise questions and have adults respond verbally to those questions. Of course, this is not to say that all adult responses are understood; nonetheless, a new and powerful mode of learning is available to the child. The essential limitation of this level is that the use of language as a tool for reflection and as an internal guide to behavior is poorly developed. Thus reasoning at this level is essentially intuitive. The final level begins at the moment at which the individual begins to ask questions, not of others, but of himself, and through the gradual "internalization" of elements of the language of argumentation acquires the ability to "talk to himself" which constitutes the essence of reflective thought and allows one to internally test alternative hypothetical statements and arrive at internally reasoned decisions to solve problems. No distinct age norms are suggested for the passing from one level of thinking to the next, yet we see no biological or psychological reason why a child as young as, say, six years old could not begin to reflect internally upon his own thoughts given an environment in which such reflective behavior was strongly encouraged. Of course this represents just a beginning and one would still require considerably more time and experience to internalize the language of argumentation and develop the associated hypothesis testing schemes. On the other hand, a dogmatic environment in which the relative merits of ideas are not discussed and rules are strictly and unthinkingly enforced would most likely retard the development of skill in using this hypothetico-deductive mode of thought.

Intuitive and Reflective Thought

This view of the development of procedural knowledge suggests that the terms *intuitive* and *reflective thought* are more descriptive of the intellectual changes that take place during adolescence than Piaget's terms *concrete* and *formal thought*. The child-like thinker is not conscious of the hypothetico-deductive nature of his/her thought processes, therefore thinking is dominated by context-dependent cues and intuitions. The adult-like thinker, on the other hand, has become conscious of his/her thought patterns and has internalized powerful patterns of argumentation which allow a conscious reflection on the adequacy/inadequacy of ideas prior to action. Reflective thinking is not based upon formal logic as Piaget claimed, but upon alternative ideas, predictions, evidence, and arguments--all mediated by language.

To emphasize the point regarding the key distinction between child-like intuitive thought and adult-like reflective thought, let us reconsider the task of forming the Mellinark. As we saw, formation of the concept of Mellinark involved hypothesis-testing behavior. If this task is given to young children they typically will not be able (by themselves) to identify the defining attributes of Mellinarks. The problem, however, poses little difficulty to the adult (reflective adult that is). Why is this so? The answer we believe is that children have

yet to become skilled in use of the necessary hypothetico-deductive pattern which allows hypotheses to be systematically generated and tested. This does not mean that children cannot develop descriptive concepts such as Mellinarks or chairs. Obviously they do. But it does mean that they do not develop the concepts themselves. They need social interaction. Specifically they need other people who have already acquired the concept to provide feedback. A young child learns the word dog and calls the neighbor's cat "doggie" and her father says "No, it's not a dog. It's a cat." Feedback may even be accompanied by additional help such as: "Dogs have floppy ears and cats have pointed ears," or "Mellinarks have a big dot, lots of little dots, and a tail." The point is that the hypothesis testing of children is often mediated by exchanges with other children and/or adults.

Another example, given by Gesell (1940) occurred in the dialogue between two children age four and five.

Four: I know that Pontius Pilate is a tree.
Five: No, Pontius Pilate is not a tree at all.
Four: Yes, it was a tree, because it says: "He suffered under Pontius Pilate," so it must have been a tree.
Five: No, I am sure Pontius Pilate was a person and not a tree.
Four: I know he was a tree, because he suffered under a tree, a big tree.
Five: No, he was a person, but he was a very pontius person. (p. 55)

Here the four-year-old is attempting to form a concept of Pontius Pilate and mistakenly hypothesizes that the words refer to a tree--a big tree. The five-year-old, however, provides contradictory feedback to the hypothesis which will cause the four-year-old to rethink his position and eventually get it right. Here the hypothesis testing takes place through dialogue. The hypothesis testing of the reflective thinking adolescent and adult, on the other hand, can be mediated internally as the reflective thinker generates hypotheses and internally checks them for consistency with other known facts before drawing a conclusion.

Notice that we have argued that the reflective thinker has "internalized" important patterns of argumentation that the intuitive thinker has not. This raises the question of just how this "internalization" takes place. According to Piaget (1976) a process called "reflective abstraction" is involved in the development of procedural knowledge. Reflective abstraction involves the progression from the use of spontaneous actions to the use of explicit verbally mediated rules to guide behavior. Reflective abstraction occurs only when the individual is prompted to reflect on his/her actions. The cause of this reflection is contradiction by the physical environment or verbally by other people as was the case of the four-year-old who believed Pontius Pilate was a tree. The result of reflective abstraction is that the person may gain accurate declarative knowledge but also becomes more aware of and skilled in use of the procedures used in gaining that knowledge. To teach science

effectively, teachers need to know how to provoke students to reflect on the status of their own declarative and procedural knowledge.

6. What Teaching Methods Best Facilitate Scientific Knowledge Acquisition?

Essential Elements of Instruction

The previous discussion suggests that the following elements must be included in lessons designed to improve both declarative and procedural knowledge:

1. Questions should be raised or problems should be posed that require students to act based upon prior beliefs (concepts and conceptual systems) and/or prior procedures.

2. Those actions must lead to results that are ambiguous and/or can be challenged/contradicted. This forces students to reflect back on the prior beliefs and/or procedures used to generate the results.

3. Alternative beliefs and/or more effective procedures should be suggested.

4. Alternative beliefs and/or the more effective procedures should now be utilized to generate new predictions and/or new data to allow either the change of old beliefs and/or the acquisition of a new belief (concept).

Suppose, for example, in a biology class students are asked to use their prior declarative knowledge (beliefs) to predict the salinity that brine shrimp eggs will hatch best in and to design and conduct an experiment to test their prediction. If students work in teams of two-three about 10-15 sets of data will be generated. These data can be displayed on the board. Because no specific procedures were given to the groups, the results will vary considerably. This variation in results then allows students to question one another about the procedures used to generate the results. It also provokes in some students the cognitive state of disequilibrium as their results are contradictory to their expectations. A long list of differences in procedures can then be generated. For example:

- *The hatching vials contained different amounts of water.*
- *Some vials were capped, others not capped.*
- *The amounts of eggs varied from vial to vial and group to group.*
- *Some eggs were stirred, others not stirred.*
- *Some groups used distilled water, others tap water, and so on.*

Once this list is generated it becomes clear to the students that these factors should not vary. Thus a better procedure is suggested. All the groups will follow the same procedure (that is variables will be controlled). When this is done, the real effect of various concentrations of salt can be separated from the spurious effects of the other variables. Finally once the new data are obtained, the results are clear and they allow students to see

whose predictions were correct and whose were not and they allow the teacher to introduce the terms "optimum range" for the pattern of hatching that was discovered. For some students this will help restore equilibrium, for other students additional activities may be necessary.

The Learning Cycle

The main thesis thus far is that situations that allow students to examine the adequacy of prior beliefs (conceptions) force them to argue about and test those beliefs. This in turn can provoke disequilibrium when these beliefs are contradicted and provide the opportunity to acquire more appropriate concepts and become increasingly skilled in using the procedures used in concept formation (i.e., reasoning patterns/forms of argumentation). The central instructional hypothesis is that correct use of the learning cycle accomplishes this end (Science Curriculum Improvement Study, 1973). Although there are the three types of learning cycles (not all equally effective at producing disequilibrium, argumentation and improved reasoning), they all follow the general three-phase sequence of exploration, term introduction and concept application introduced earlier.

During exploration, students often explore a new phenomenon with minimal guidance. The new phenomenon should raise questions or complexities they cannot resolve with their present conceptions or accustomed patterns of reasoning. In other words, it provides the opportunity for students to voice potentially conflicting, or at least partially inadequate, ideas. This can spark debate and an analysis of the reasons for their ideas. That analysis can then lead to an explicit discussion of ways of testing alternative ideas through the generation of predictions. The gathering and analysis of results then can lead to a rejection of some ideas and the retention of others. It also allows for a careful examination of the *procedures* used in the process. A key point is that allowing for initial exploration allows students to begin to interact with the phenomena in a very personal way which can have a very profound effect on not only their observational skills but on their hypothesis generation and testing skills as well.

Three Types of Learning Cycles

Learning cycles can be classified as one of three types--descriptive, empirical-abductive and hypothetical-deductive. The essential difference among the three is the degree to which students either gather data in a purely descriptive fashion (not guided by explicit hypotheses they wish to test) or initially set out to test alternative hypotheses in a controlled fashion. The three types of learning cycles represent three points along a continuum from descriptive to experimental science. They obviously place differing demands on student initiative, knowledge, and reasoning skill. In terms of student reasoning, descriptive learning cycles generally require only descriptive patterns (e.g., seriation, classification, conservation) while hypothetical-deductive learning cycles demand use of higher order patterns (e.g., controlling variables, correlational reasoning,

hypothetico-deductive reasoning). Empirical-abductive learning cycles are intermediate and require descriptive reasoning patterns, but generally involve some higher-order patterns as well.

In *descriptive learning* cycles students discover and describe an empirical pattern within a specific context (exploration). The teacher gives it a name (term introduction), and the pattern is then identified in additional contexts (concept application). This type of learning cycle is called descriptive because the students and teacher are describing what they observe without attempting to explain their observations. Descriptive learning cycles answer the question "What?" but do not raise the causal question "Why?"

In *empirical-abductive* learning cycles students again discover and describe an empirical pattern in a specific context (exploration), but go further by generating possible causes of that pattern. This requires the use of analogical reasoning (abduction) to transfer terms/concepts learned in other contexts to this new context (term introduction). The terms may be introduced by students, the teacher, or both. With the teacher's guidance, the students then sift through the data gathered during the exploration phase to see if the hypothesized causes are consistent with those data and other known phenomena (concept application). In other words, observations are made in a descriptive fashion, but this type of learning cycle goes further to generate and initially test a cause(s), hence the name empirical-abductive.

The third type of learning cycle, *hypothetical-deductive*, is initiated with the statement of a causal question to which the students are asked to generate alternative explanations. Student time is then devoted to deducing the logical consequences of these explanations and explicitly designing and conducting experiments to test them (exploration). The analysis of experimental results allows for some hypotheses to be rejected, some to be retained and for terms to be introduced (term introduction). Finally the relevant concepts and reasoning patterns that are involved and discussed may be applied in other situations at a later time (concept application). The explicit generation and test of alternative hypotheses through a comparison of logical deductions with empirical results is required in this type of learning cycle, hence the name "hypothetical-deductive."

The following steps are gone through in preparing and using the three types of learning cycles:

1. Descriptive learning cycles
    a. The teacher identifies some concept(s) to be taught.
    b. The teacher identifies some phenomenon that involves the pattern upon which the concept(s) is based.
    c. Exploration Phase: The students explore the phenomenon and attempt to discover and describe the pattern.

d. Term Introduction Phase: The students report the data they have gathered and they and/or the teacher describe the pattern; the teacher then introduces a term(s) to refer to the pattern.
e. Concept Application Phase: Additional phenomena are discussed and/or explored that involve the same concept.

2. Empirical-abductive learning cycles
   a. The teacher identifies some concept(s) to be taught.
   b. The teacher identifies some phenomenon that involves the pattern upon which the concept(s) is based.
   c. Exploration Phase: The teacher raises a descriptive *and* causal question.
   d. Students gather data to answer the descriptive question.
   e. Data to answer the descriptive question are displayed on the board.
   f. The descriptive question is answered and the causal question is raised.
   g. Alternative hypotheses are advanced to answer the causal question and the already gathered data are examined for their initial test.
   h. Term Introduction Phase: Terms are introduced that relate to the explored phenomenon and to the most likely hypothesized explanation.
   i. Concept Application Phase: Additional phenomena are discussed or explored that involve the same concept(s).

3. Hypothetical-deductive learning cycles
   a. The teacher identifies some concept(s) to be taught.
   b. The teacher identifies some phenomenon that involves the pattern upon which the concept(s) is based.
   c. Exploration Phase: The students explore a phenomenon that raises the causal question or the teacher raises the casual question.
   d. In a class discussion, hypotheses are advanced and students are told either to work in groups to deduce implications and design experiments or this step is done in class discussion.
   e. The students conduct the experiments.
   f. Term Introduction Phase: Data are compared and analyzed, terms are introduced and conclusions are drawn.
   g. Concept Application Phase: Additional phenomena are discussed or explored that involve the same concept(s).

Descriptive learning cycles. It was stated earlier that the three types of learning cycles are not equally effective at generating disequilibrium, argumentation, and the use of reasoning patterns to examine alternative conceptions/misconceptions. Descriptive learning cycles are essentially designed to have students observe a small part of the world, discover

a pattern, name it and look for the pattern elsewhere. Little or no disequilibrium may result, as students will most likely not have strong expectations of what will be found. Graphing a frequency distribution of the length of a sample of sea shells will allow you to introduce the term "normal distribution" but will not provide much argumentation among your students. A descriptive learning cycle into skull structure/function allows the teacher to introduce the terms herbivore, omnivore and carnivore. It also allows for some student argumentation as they put forth and compare ideas about skull structure and possible diets. Yet seldom are possible cause-effect relationships hotly debated, and hard evidence is not sought.

Empirical-abductive learning cycles. In contrast, consider the empirical-abductive (EA) learning cycle called "What Caused the Water to Rise?" described below which involves the concept of air pressure. It, like other EA learning cycles, requires students to do more than describe a phenomenon. An explanation is required. Explanation opens the door to a multitude of misconceptions. The resulting arguments and analysis of evidence represent a near perfect example of how EA learning cycles can be used to promote disequilibrium and the acquisition of conceptual knowledge and the development of procedural knowledge.

To start, students invert a cylinder over a candle burning in a pan of water. They observe that the flame soon goes out and water rises into the cylinder. Two causal questions are posed. Why did the flame go out? Why did the water rise? The typical explanation students generate is that the flame used up the oxygen in the cylinder and left a partial vacuum which "sucked" water in from below. This explanation reveals two misconceptions:

1. Flames destroy matter thus produce a partial vacuum, and
2. Water rises due to a nonexistent force called suction.

Testing of these ideas requires use of the hypothetico-deductive pattern of reasoning and utilizing the isolation and control of variables (see Figure 5).

Hypothetical-deductive learning cycles. Like EA learning cycles, hypothetical-deductive (HD) learning cycles require explanation of some phenomenon. This opens up the possibility of the generation of alternative conceptions/misconceptions with the resulting argumentation, disequilibrium and analysis of data to resolve conflict. However, unlike EA cycles, HD cycles call for the immediate and explicit statement of alternative hypotheses to explain a phenomenon. In brief, a causal question is raised and students must explicitly generate alternative hypotheses. These in turn must be tested through the deduction of predicted consequences and experimentation. This places a heavy burden on student initiative and thinking skills.

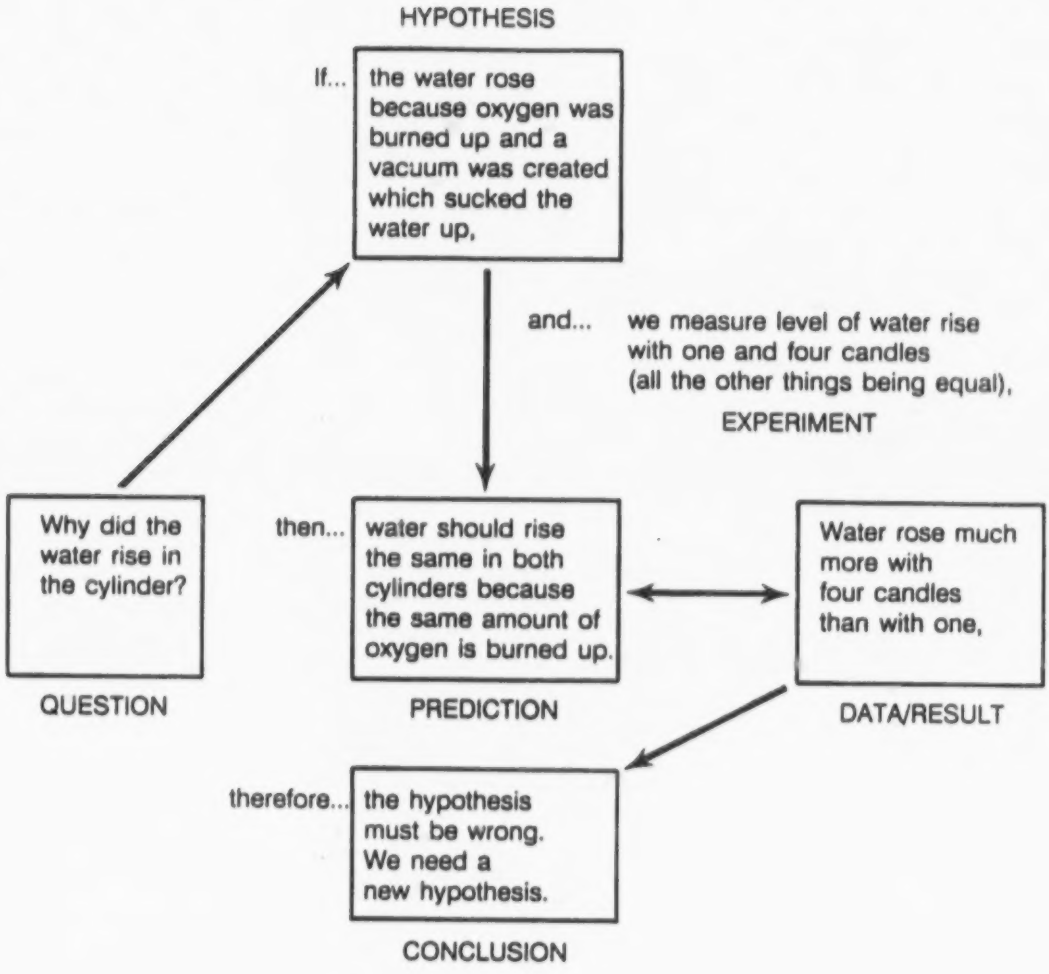

HYPOTHESIS
If...
the water rose because oxygen was burned up and a vacuum was created which sucked the water up,
and...
we measure level of water rise with one and four candles (all the other things being equal),
EXPERIMENT
Why did the water rise in the cylinder?
QUESTION
then...
water should rise the same in both cylinders because the same amount of oxygen is burned up.
PREDICTION
Water rose much more with four candles than with one,
DATA/RESULT
therefore...
the hypothesis must be wrong. We need a new hypothesis.
CONCLUSION

Figure 5. The box on the left represents the key question raised. In this case it is "Why did the water rise?" The subsequent hypotheses, experiments, predictions, results, and conclusions follow the hypothetico-deductive if . . . and . . . then . . . therefore . . . pattern of reasoning and require students to isolate and control independent variables in comparison to water rise with one and four candles. As shown, the initial hypothesis leads to a false prediction, thus must be rejected(reasoning to a contradiction). Students must now generate an alternative hypothesis or hypotheses and start over again until they have a hypothesis that is consistent with the data (i.e., not falsified).

Consider, for example, the question of water rise in plants. Objects are attracted toward the center of the earth by a force called gravity, yet water rises in tall trees to the uppermost leaves to allow photosynthesis to take place. What causes the water to rise in spite of the downward gravitational force? The following alternative hypotheses (alternative conceptions/misconceptions) were generated in a recent biology lab:

1. Water evaporates from the leaves to create a vacuum which sucks water up,
2. Roots squeeze to push water up through one-way valves in the stem tubes,
3. Capillary action of water pulls it up like water soaking up in a paper towel, and
4. Osmosis pulls water up.

Of course equipment limitations keep some ideas from being tested, but the "leaf evaporation" hypothesis can be tested by comparing water rise in plants with and without leaves. This requires the reasoning patterns of isolation and control of variables. The "root squeeze" hypothesis can be tested by comparing water rise in plants with and without roots; the "one-way valve" hypothesis can be tested by comparing water rise in right-side-up and upside-down stems. Results allow rejection of some of the hypotheses and not others. The survivors are considered "correct," for the time being at least, just as is the case in doing "real" science, which of course is precisely what the students are doing. Following the experimentation, terms such as transpiration can be introduced and applied elsewhere as is the case for all types of learning cycles.

Learning Cycles as Different Phases of Doing Science

A look back at Figures 4 and 5 will serve to summarize the major differences among the three types of learning cycles described. Descriptive learning cycles start with explorations which tell us what happens under specific circumstances in specific contexts. They represent descriptive science. In the context of the candle burning experiment they allow us to answer questions such as "How high and how fast will the water rise under varying conditions?" But they stop before the question "What causes the water to rise?" is raised. Empirical-abductive learning cycles include the previous, but go further and call for causal hypotheses. Thus, they include both the question and hypotheses boxes of Figures 4 and 6 and may go even further to include some or all of the subsequent boxes. Hypothetical-deductive learning cycles generally start with a statement of the causal question and proceed directly to hypotheses and their test, thus represent the classic view of experimental science. To teach science effectively, teachers need to know what the learning cycle method of teaching is and how to use it.

Concluding Remarks

I believe that the educational system should help students (a) acquire sets of meaningful and useful concepts and conceptual systems, (b) develop skill in using the thinking patterns essential for independent, creative and critical thought, and (c) gain

confidence in their ability to apply their knowledge to learn, to solve problems, and to make carefully reasoned decisions. The preceding pages have presented a theory of knowledge construction and a compatible instructional theory. Those theories argue that the most appropriate way, perhaps the only way, to accomplish these objectives, is to teach in a way that allows students to reveal their prior conceptions and test them in an atmosphere in which ideas are openly generated, debated, and tested, with the means of testing becoming an explicit focus of classroom attention. Correct use of the learning cycle teaching method allows this to happen. The two theories can be summarized by the following postulates:

A Theory of Knowledge Construction

1. Children and adolescents personally construct beliefs about natural phenomena, some of which differ from currently accepted scientific theory.

2. These alternative beliefs (misconceptions) may be instruction-resistant impediments to the acquisition of scientifically valid beliefs (conceptions).

3. The replacement of alternative beliefs requires students to move through a phase in which a mismatch exists between the alternative belief and the scientific conception and provokes a "cognitive conflict" or state of mental "disequilibrium."

4. The improvement of thinking skills (procedural knowledge) arises from situations in which students state alternative beliefs and engage in verbal exchanges where arguments are advanced and evidence is sought to resolve the contradiction. Such exchanges provoke students to examine the *reasons* for their beliefs.

5. Argumentation provides experiences from which particular forms of argumentation (i.e., patterns of thinking) may be internalized.

A Theory of Instruction

1. The learning cycle is a method of instruction that consists of three phases called exploration, term introduction, and concept application.

2. Use of the learning cycle provides the opportunity for students to reveal alternative beliefs and the opportunity to argue and test them, thus become "disequilibrated" and develop more adequate conceptions and thinking patterns.

3. There are three types of learning cycles (descriptive, empirical-abductive, hypothetical-deductive) that are not equally effective at producing disequilibrium and improved thinking skills.

4. The essential difference among the three types of learning cycles is the degree to which students either gather data in a purely descriptive fashion or initially set out to test explicitly alternative beliefs (hypotheses).

5. Descriptive learning cycles are designed to have students observe a small part of the world, discover a pattern, name it, and seek the pattern elsewhere. Normally only descriptive thinking skills are required.

6. Empirical-abductive learning cycles require students to describe and explain a phenomenon and thus allow for alternative conceptions, argumentation, disequilibrium, and the development of higher order thinking skills.

7. Hypothetical-deductive learning cycles require the immediate and explicit statement of alternative conceptions/hypotheses to explain a phenomenon and require higher order thinking skills in the test of the alternatives.

A considerable amount of research has been conducted which supports the notion that correct use of the learning cycle in the science classroom is highly effective in helping students obtain the stated objectives.

In summary then, to effectively teach science, teachers need to know

- That science is a creative hypothetico-deductive enterprise;
- That the central objective of science teaching is to help students develop creative and critical thinking skills;
- The major theories that comprise the structure of the disciplines within science;
- How to think scientifically;
- How scientific knowledge (both declarative and procedural) is acquired by students; and
- How to use learning cycles to guide students as they construct their own scientific knowledge.

Of course, it would help immensely if education policymakers knew this as well.

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WHAT TEACHERS NEED TO KNOW TO TEACH SCIENCE EFFECTIVELY

Arnold A. Strassenburg[3]

Comments on Anderson's Paper

The paper by Charles Anderson contains, in my view, an extremely good answer to the question posed by the organizers of this conference. The roughly equal emphasis on social and pedagogical knowledge, knowledge of science, and knowledge of students seems to me to be intuitively sensible and well supported by empirical evidence. His statement that "there is strong reason to doubt whether science process skills exist at all" (p. 10) is provocative and open to challenge. In my view, it is too extreme; I believe it is possible and meaningful to identify processes that are characteristic of what scientists do. The emphasis on these process skills, as it has permeated the writings of science educators in recent years, is not justified by the notion that process is more important that content, but rather because it calls attention to the need to deny that science is defined by its content, especially if that content is represented by scientific facts.

I do assert, however, that any attempt to teach process in isolation from content will turn out to be a sterile exercise. It would be like trying to teach effective communication when the student knows nothing worth communicating. Content and process must be taught as intertwining components of science. This paper will focus primarily on what teachers need to know about content and process to be successful in teaching science. The choice of such a narrow focus is not meant to imply that social and pedagogical knowledge or knowledge of students is less important, but rather to assert that this author can add most to Anderson's contribution by focusing on knowledge of science.

What Content Knowledge Is Important

The answer to this question is constrained by theoretical as well as practical considerations. First, let us ask, What *kinds* of knowledge must teachers have about science content? Second, What knowledge about science process must teachers have to convey the content knowledge effectively? Third, How can teachers acquire this knowledge most efficiently?

To answer the first question, we begin by asserting that no single scientific fact is essential to a teacher's effectiveness in teaching science. What is most important is for teachers to portray science as a way of making sense of natural phenomena; to do so successfully does not require knowledge of any particular fact. It does call for the

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formulation of questions about natural phenomena and the gathering of relevant data, the formulation of hypotheses for explaining the phenomena--which means relating them to other phenomena that are better understood--and the design of procedures for testing whether or not the hypotheses are consistent with observations.

Science

If facts are not by themselves important and processes are meaningless when isolated from content, What content knowledge should teachers know? We believe the answer is "a small number of unifying principles." Any recitation of these principles puts us in danger of including some that some scientists view as extremely important. Without making a claim that our list is the only list that could be defended, we will nevertheless offer a representative list of important principles:

1. The universe consists of many galaxies, each galaxy consists of many stars, and our star (the sun) has planets revolving around it. These objects evolved, under the force of gravity, from matter that was ejected from a local source after an explosion that took place about 20 billion years ago.

2. Our planet is one of nine that rotate about the sun in our solar system. Physically it consists of continents that move slowly but steadily in response to convection currents in a hot, liquid core (radioactivity is the source of heat), oceans that fill ocean beds that are constantly expanding or contracting due to the welling up of magma from the core or the subduction of solid material as one continental plate slides below another, and an atmosphere of gases that reflect both the volatile matter of the primordial earth and the results of evolutionary geological and biological processes.

3. All matter consists of small particles called molecules; each molecule consists of a specified combination of atoms (only about 100 distinct kinds of atoms exists); and each atom in turn consists of a massive, positively charged nucleus surrounded by a layered cloud of low-mass, negatively charged particles called electrons.

4. Electrical forces between two or more atoms not only produce stable molecules but also cause rearrangements of the electron configurations that result in the dissociation of stable molecules. These processes are known as chemical reactions.

5. Nuclear forces between the constituent particles of one or more nuclei result in changes in molecular structures; these processes are known as nuclear reactions, and each such reaction involves an energy change about 10^5 times greater in magnitude than the energy change in an individual chemical reaction.

6. Energy takes a small number of different forms that depend on such things has the amount of matter involved in an interaction, the electrical charge on each particle of matter, the state of motion of each particle, and the relative positions of the interacting particles.

For an isolated system of interacting particles the sum of all kinds of energy is a quantity that remains constant in time no matter how the particles interact.

7. On the level of molecules, atoms, and electrons, motion is the normal state of affairs. Changes in motion--speeding up, slowing down, or deflecting the directions of particles--are caused by forces between the particles--gravitational, electromagnetic, and nuclear. As a result of these motions, the configurations of positions and energies of the particles of an isolated system become ever more random. On a macroscopic scale, this has the effect of making energy less and less available to do useful work.

8. On the level of macroscopic objects, there are laws that specify precisely how each object will move under the influence of the forces exerted on it. On the level of atoms and their constituent particles, the laws that govern their behavior are statistical in nature.

9. On the level of macroscopic objects, measurable quantities such as the total energy of a system of interacting objects can take on any of a continuum of values. On the level of nuclei, atoms, and molecules, these same measurable quantities are often confined to a discrete set of quantized values.

10. Life on earth consists of an enormous variety of animals, plants, and simple organisms such as bacteria and viruses.

11. All living things consists of one or more cells. Cells are small factories that can extract energy from nutrients, synthesize proteins that are essential to the organisms growth and health, eject waste materials, and replicate themselves.

12. Living organisms reproduce by transmitting to the offspring a large, coded molecule called DNA. The offspring exhibit traits that are similar to the traits of both parents but different in detail from either. The differentiation leads to a great diversity of individuals, but natural selection limits the survivors to a large but finite number of species, where each member of a species has characteristics that are similar to all other members. Over long periods of time, the number and characteristics of the species evolve; the nature of the evolution is dictated by a combination of random chance matings, the influence of environmental conditions, and occasional mutations of the DNA.

13. Human beings are different from other organisms because they can communicate with one another efficiently, maintain records of past experiences, and contemplate reasons for and consequences of their own behaviors.

14. Human beings tend to interact strongly and in so doing they develop cultures characterized by common social, political, and economic institutions. Cultural mores and taboos exert strong influences on the behaviors of individuals so that members of one culture are easily distinguishable from those of another, and conflicts between the members of two cultures occur with regrettable frequency.

15. Human beings require food to survive and grow. During the approximately two million years of human existence humans have evolved from hunters and gatherers of other

organisms, through a phase where every tribe of humans cultivated the plants and animals it needed to survive, to the current economy in which a small percentage of people grow, raise, and distribute the food needed by all.

16. Humans beings are inventive and have devised ways to produce materials from which to manufacture products needed to simplify and enrich daily life and methods of extracting and transporting the energy which powers the factories, maintains comfortable conditions in homes and workplaces, and moves the vehicles of transportation. The heavy reliance on fossil fuels, characteristic of the past and still prevalent today, has created two problems that demand the search for and adoption of new energy sources: pollution and the exhaustion of available fossil fuels.

17. Human beings communicate with each other both to experience the joy of sharing ideas and experiences and to increase the effectiveness of their shared manufacturing, agricultural, and educational activities. The efficiency of communication has historically experienced sudden increases as a result of (a) the development of written language, (b) the invention of the printing press, (c) the discovery of electromagnetic radiation and the invention of devices to control its transmission, and (d) the invention of the computer.

18. Human beings (and other animals) are subject to diseases caused by both the invasion of their bodies by very small organisms (bacteria and viruses) and the deterioration of body organs resulting from accidents, radiation, toxic chemicals, and old age. Enormous progress has been made in controlling infectious diseases; most are no longer major causes of death. Slower progress is being made in identifying what substances and lifestyles place one in jeopardy, and in persuading individuals and society as a whole to modify harmful behaviors.

Technology

As demanding as it may be for a teacher--particularly one in the lower grades who must also teach reading, arithmetic, and other subjects in addition to science--to master the above list of natural science and social science principles, to do so would not, by itself, assure competent science teaching. Science can only be made relevant and exciting to large numbers of students if its roles in stimulating technological advances and supporting engineering practice are made explicit. Not every teacher of science should be expected to know details about what engineers do and how technologies evolve. The manner in which scientific knowledge, economic circumstances, and social patterns interact to determine which technologies thrive is too complex to reveal to grade-school children. What is possible and desirable is for teachers to include in their science instruction a few case studies of specific technologies that developed rapidly after the advent of critical science discoveries and, conversely science discoveries that were made possible by technological developments. Since

college science courses rarely include such information, special efforts are necessary if teachers are to acquire the knowledge to make this possible.

Mathematics

Inasmuch as virtually every elementary school teacher teaches mathematics, and every middle school and secondary school science teacher learned a substantial amount of mathematics in conjunction with their science courses, knowledge of an adequate amount of mathematics may appear not to be a problem for the teaching of science. Actually there often is a problem. The mathematics that teachers know and teach does not always support the teaching of science. For example, teachers in the lower grades teach primarily arithmetic. While number manipulation is essential to many science units, by itself it is not sufficient to allow students to grasp the relationships between the variables that characterize scientific investigations. What follows is a list of quantitative activities that every science teachers needs to master:

1. **Symbolic relationships.** At some grade levels it will suffice to be able to express these in words. At other levels it may be essential to express them graphically. At still higher levels, algebraic relationships may be especially helpful. Teachers need to be able to function at all these levels and to know which is most appropriate in particular situations.

2. **Geometric relationships and scale.** It is often true that scientific ideas can be clearly expressed using geometrical representation. Teachers need to be comfortable and generally conversant with the properties of common shapes and figures. It is not important that teachers memorize geometrical formulas, such as how to calculate the surface of a sphere given its radius, but it is extremely useful for them to understand notions of scaling. For example, to know that the volume of an object increases more rapidly than its surface area as the object gets larger helps students to understand why there are upper limits to the size of animals, mountains, and buildings.

3. **Uncertainty.** Most mathematics courses deal with equations, not inequalities, and treat all numbers as if they represented the result of counting a set, not as if they represented a measurement with its inherent error. Teachers need to help students (a) estimate the size of quantities from visual observations and other forms of incomplete information, (b) perform order-of-magnitude calculations when the relevant data are known only approximately, (c) recognize that errors of measurement limit the precision of all experimental result, and (d) understand that the complexity of some situations forces us to settle for statements about the gross behavior of the system and to forego attempts to describe the detailed behavior of individual components of the system.

4. **Reasoning.** Scientists need to make inferences concerning possible interpretations of incomplete sets of data, to deduce logical conclusions from known facts and assumption, and to use induction to generalize from the result of a finite set of particular examples. The

dynamic processes are closer to the true essence of science than any collection of facts or theories; thus students need to participate in these processes if they are to acquire an appreciation for the scientific enterprise. Teachers must not only be able to help students through reasoning processes, but they should be able to help students distinguish among (a) conclusions that are true because the premises are true and the logic is correct, (b) conclusions that are not necessarily true because the logic is faulty even through the premises are correct, (c) conclusions that are not necessarily true because the premises are questionable even though the logic is correct, and (d) conclusions that are probable but not proven because one can never be certain that specific examples, no matter how numerous, lead to a valid generalization (most scientific theories fit in this category).

5. **Problem solving.** Mathematics courses often present problems that can be solved by applying an algorithmic procedure to given data. Problem solving in science is seldom of this nature. Often the data one needs are not specified or are known incompletely. Even more often, the steps for solving the puzzle are not clearly indicated. Since ingenuity frequently permits the use of shortcuts that eliminate tedious work, thought about method is valuable and variations in approach among the members of a class are inevitable. Teachers need to have experienced success in this kind of problem solving, and to be skillful at recognizing when a solution is valid as well as the advantages and disadvantages of alternate approaches.

History

At least as important as being able to give an explanation for a related set of phenomena is to be able to explain why the explanation is believed or should be believed. Clearly part of any such justification will be based on logic. I believe that gravity is an inverse square law in part because assuming this force law leads one to predict that planets and comets should execute conic section orbits about the sun, and observation reveals that they do.

However, no one person can personally make all the observations that provide convincing input to the proposed explanation of natural phenomena. We are forced to rely on accounts of the results of crucial experiments performed in the past. I believe in the conservation of energy, not because I have personally verified the law in diverse circumstances, but because I am familiar with Rumford's work on the boring of cannons, Maxwells' synthesis of the work of Coulomb and Faraday concerning electromagnetic interactions, Einstein's interpretation of the photoelectric effect, Boethe's explanation of radiation from the sun, and so forth. If teachers are to provide students with convincing reasons to believe the explanation commonly accepted by scientists, they must be families with some landmark experiments.

Of course, no teacher--not even every scientist--can know the history of science so well that he/she can be prepared to answer correctly and immediately every time a student asks "Why should I believe this particular explanation?" What *can* be expected of teachers to encourage students to ask such questions, the poise to say "I don't know the answer now, but I know how we can find a good answer," and familiarity with sources of good answers.

What Teachers Need to Know About Science Processes

I said earlier that I do not believe science processes can be or should be taught separate from science content. Nevertheless, some processes are essential to the scientific enterprise, so it is important for a teacher to know which processes are especially important and to plan student activities consciously to allow students to gain familiarity with and an appreciation of such processes. I do not believe that it is possible or worthwhile to develop a list that includes, without ambiguity or redundancy, every process that is important to science. I am convinced of this because every scientist I know denies the existence of a unique--the "scientific method"--that is followed by all science workers. When asked how he or she functions, each will describe a process that has unique features, some of which will seem to others to be unsystematic and even mystical. I do believe it is possible and worthwhile to develop a short list of processes that the vast majority of scientists would agree are important. Here is my effort to produce such a list:

1. **Observation.** Careful observation is an acquired skill. Most persons who observe a scene or an event remember only selective parts of what they observed and these imperfectly. Even trained observers will miss details. Thus it is important for a successful experimenter not only to observe carefully but to know in advance what parts of the whole need special attention. No single idea is more important to convey to science students than the notion that science is an effort to understand--to describe and to explain--the behavior of natural and social systems. Clearly it is possible to become aware of the behaviors of interest by letting someone who has observed them directly describe them to others who have not made direct observation. However, a large amount of evidence has convinced all who have studied how students learn science that there are enormous benefits when students observe phenomena personally. Thus, teachers need to provide their students with opportunities to observe and describe phenomena that can serve as a focus for fruitful study. Teachers are unlikely to guide such work along productive paths unless they have themselves has similar opportunities, guided by someone who focused the observations, and the subsequent development of explanations, by formulating appropriate questions.

2. **The development of hypotheses.** Even when one's knowledge about a set of related phenomena is of a rudimentary nature, it is natural and useful to speculate about causes of the observed behavior. I know from experience that students will enthusiastically participate in this process if encouraged to do so. What teachers must know to provide the

encouragement is (a) that hypotheses making is an essential part of doing science and (b) that all proposed hypotheses deserve consideration. To reject a suggestion out-of-hand is antithetical to good science.

3. **The design of experiments to test the validity of an hypothesis.** Since the goal of science is to explain observed behavior, the testing of hypotheses is as important as their original formulation. While the testing may require less in the way of inventiveness, it is much more demanding with regard to design details. The experimenter must first be precise about the effect to be studied (the dependent variable) and how it should be measured. He/she must also speculate on what independent variables might influence the result and design a way to hold all but one constant. Repeated runs may be necessary, both to explore the magnitude of random errors and to test the influence of several independent variables.

Teachers must know how to conduct such controlled experiments. They need to recognize when student designs are adequate and how to suggest improvements without completely removing control of the process from the student. It is surely true that teachers will be unable to exhibit these skills unless they have been challenged to design experiments themselves at earlier times.

4. **Recording, manipulating, and displaying experimental data.** Clearly accurate and appropriate records need to be kept as an experiment proceeds. Accuracy results in part from selecting suitable instruments and in part from knowing techniques for using them properly. Appropriateness requires a clear understanding in advance of what parameters need to be varied and the range of each variable. In addition, adequate records require that the recorder approach the task in an organized fashion.

Manipulating data involves mathematics. Clearly the essential mathematical procedures must be identified and carried out systematically and with a minimum of error. The optimum way to display data is, to some extent, a matter of choice. Because graphical displays are frequently used and appear to be more readily understood than other methods, teachers need to be familiar with graphing techniques and prepared to assist students who are still struggling with the subtleties of these techniques.

5. **Drawing conclusions from experimental results.** Obviously no scientists could earn a living unless they could perform this process well; it is in a sense, the most important process of all. Unfortunately, it is also the most difficult. For various reasons, including faulty experimental design and limitations in the precision of measurements, experiments are often inconclusive. The statistical techniques that allow one to estimate quantitatively the probability that the hypotheses is true are so intricate as to be out of place at the school level. Even so it is essential for a teacher to convey to students some sense of whether the results are consistent or inconsistent with the hypotheses. Since this would be impossible to do without introducing the notion of experimental error, teachers need to know a bit about measurement error and how it influences the interpretation of experimental results.

How Can Teachers Acquire the Knowledge of Science Content and Process That They Need

Preservice Teacher Education

Much of the burden of preparing teachers for effective science teaching rests with the institution that provided their undergraduate courses in science, mathematics, and science teaching methods. An issue of paramount importance is that science should be taught to prospective teachers in the same manner that they will later be expected to teach science to children. This must include opportunities to observe phenomena, plan and conduct controlled experiments, and infer from their results explanations for phenomena that have been selected for study.

It is probably too much to expect that prospective teachers will learn to feel comfortable with their knowledge about the 18 unifying principles listed earlier in this paper during their undergraduate years. They will certainly not achieve this state by enrolling in a few introductory courses in the physical, biological, and social sciences as these are typically taught to liberal arts majors. Courses that are specifically designed to provide the kind of science preparation described in this paper are badly needed and would be valuable to many undergraduates who have no plans to teach in the schools as well as those who do. The science courses that prospective teachers take as undergraduates should emphasize explanation of how the universe works, not facts about the universe. They should encourage the students to ask "Why should I believe these explanations?" and provide teachers with information about how convincing evidence supporting major theories has been obtained by scientists as well as opportunities to gather modest amounts of such evidence on their own initiative.

Prospective teachers need to learn the mathematical skills listed earlier in this report before they attempt any science teaching. The elementary mathematics courses taught at most universities do not teach, in a single course, this particular collection of skills. In fact some of these skills--uncertainty and estimation, for example--may not be taught formally in any mathematics course. Perhaps some or all of these topics should be included in a science teaching methods course.

The final comments I wish to make about a science teacher's preservice preparation concerns the methods course. For much the same reason that science content and the processes of science teaching methods cannot be taught effectively in isolation from one another, I believe that science teaching methods cannot be taught effectively from science content courses. One model that could work well is collaboration between a scientist who teaches the unifying principles and a science educator who teaches methods appropriate for exploring phenomena related to the principles under study. The exploration would, of

course, involve using--and thus learning--the science processes teachers need to know. If university professors teach the content and process knowledge as school teachers should, then future teachers will learn methods of science teaching the best possible way: by example.

Inservice Teacher Education

Good teaching is so demanding and science knowledge grows so rapidly that we should never expect that four--or even five--years of preservice education will prepare a teacher to teach science for a lifetime. Periodic opportunities for teachers to update their science knowledge, to learn about new educational research results and instructional materials, and to share teaching strategies with other teachers should always be provided. Considerable experience with this process has convinced me that the best model for inservice science education includes a several-week summer program patterned after the preservice science experiences I have described above followed by a series of academic year interactions. The purpose of the latter is to provide opportunities to examine the results of innovations planned during the summer meeting and to devise modifications that would produce more effective results. (I am convinced that "inservice days" sprinkled throughout the academic year are not effective in improving science teaching.) The cost of sending every teacher to such a program is prohibitive. What *is* feasible is for one teacher in every school district to attend each year, and for that teacher to become a resource for other teachers in the district.

Continuous Education Through Professional Contacts

Teachers are professionals. Like professionals in other fields, they need to interact with others who have responsibilities similar to theirs to discuss problems, to learn about new developments in the disciplines they teach, and to exchange ideas about pedagogy. Informal contacts with other teachers and educators can contribute much to this process.

A more formal method of keeping on top of new developments and filling in the holes in a teacher's preservice preparation is to join a professional society. Typically the journals and meetings of such societies are filled with exactly the kinds of needed information that have been outlined in earlier sections of this paper. No grade school teacher can afford the time or money to belong a professional society in each of the disciplines he/she teaches. However, it should be possible--and school administrators should help to orchestrate this--for one teacher in every building to be active in a professional science teaching society and for that person to share the benefits of membership with colleagues in the building.

As Anderson said so convincingly in his paper, progress toward more effective science teaching will come only as the result of incremental improvements on many fronts

simultaneously. Public interest in such progress is high. Let us begin now to coordinate our steps forward.

TEACHING MATHEMATICS FOR UNDERSTANDING: WHAT DO TEACHERS NEED TO KNOW ABOUT THE SUBJECT MATTER?

Deborah Loewenberg Ball[4]

Mathematics--With and Without Understanding

Mathematics education is in trouble in this country and the signs of it are everywhere. The most recent outcry appeared just last month in the National Research Council 1989 report, *Everybody Counts*. The document opens with this assertion:

> Three out of four Americans stop studying mathematics before completing either career or job prerequisites. Most students leave school without sufficient preparation in mathematics to cope with either on-the-job demands for problem-solving or college expectations for mathematical literacy. . . . Our country cannot afford continuing generations of students limited by lack of mathematical power to second-class status in the society in which they live. (p. viii)

And, in his new book, *Innumeracy*, John Paulos (1988) points out that "innumeracy, an ability to deal with the fundamental notions of number and chance, plagues far too many otherwise knowledgeable citizens" (p. 3). He suggests that, in fact, mathematical literacy is not seen as important by many well educated people who are unashamed to flaunt their lack of mathematical understanding. "I just don't have a mathematical mind," is the common explanation.

The most recent results of the National Assessment of Educational Progress support these assertions. It is true that most students were accurate with simple number facts. However, beyond that the picture was bleak. Quite a few students lacked proficiency with basic computation and word problems. Only about half of the 17-year-olds and one-fifth of the 13-year-olds were able to apply mathematical knowledge to so-called moderately complex problems, problems such as calculating the area of a 6 x 4 cm rectangle or responding to a question like, "Which of the following is true of 87% of 10? (a) It is greater than 10; (b) It is less than 10; It is equal to 10." And almost none of the students at any age were able to solve multistep problems (Dossey, Mullis, Lindquist, and Chambers, 1987). Although mathematical competence is an essential component of a good education, these results (as well as many other indicators) suggest that many students are failing to learn even rudimentary concepts about and procedures for working with quantities and space. What

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they do learn, they learn without understanding. And, additionally troubling, this failure is disproportionately distributed among black and Hispanic students, as well as females.

Why is this? One route to making sense of this state of affairs is to try an example on yourself, for you, too, are a product of American mathematics education. Do you remember how you were taught to divide fractions? Take the following:

$$1\ 3/4 \div \tfrac{1}{2}$$

Do you remember how to "do" this--how to calculate the answer?[5] Now, can you think of a situation in the real world for which $1\ 3/4 \div \frac{1}{2}$ is the mathematical formulation? In other words, what does what you just did *mean*? How do you get an answer like *3½* for this?

Most commonly, people who are asked this, make up a story something like this: "You have 1 3/4 pizzas and you want to share them equally between two people." This seems to make sense because 1 3/4 pizzas are imagined as being divided into four pieces each. Thus, if you divide seven pieces of pizza between two people, each one gets 3½ pieces of pizzas. But this story represents $1\ 3/4 \div 2$, not $1\ 3/4 \div \frac{1}{2}$. To divide something *in* half means to divide it into two equal parts (÷ 2); to divide something *by* one-half means to form groups of ½:

4 ÷ 1/2 = 8

There are eight halves in 4 wholes.

4 ÷ 2 = 2

There are two groups of two in 4 wholes.

The 3½ pieces of pizza in the common story that most people construct represent 3½ *fourths*, not 3½ *halves*. An appropriate story should actually be something like, "If you have 1 3/4 yards of fabric, how many ½-yard lengths can you cut?" Then the answer, 3½ ½-yard lengths makes sense.

Why people who have "had" mathematics in school can get answers without knowing what they mean or what they relate to is due to the way mathematics is typically taught. Researchers who have studied math teaching and learning (e.g., Good, Grouws, and Ebmeier, 1983; Goodlad, 1984; Madsen-Nason and Lanier, 1986, Stodolsky, 1988) paint a picture that is all too familiar to anyone who has made his or her way through 12 years of public school: In most math classes, the teacher stands at the board, shows students how to

[5]Traditionally this is taught via the rule "invert and multiply." In this case, that means converting 1 3/4 to 7/4 and "flipping" ½ to 2/1 and multiplying the two numbers. The result: 3½.

go through the steps of a particular procedure, and then assigns practice exercises. For example, if the topic were division of fractions, students would be shown how to invert and multiply. They might be told that dividing by a fraction is "the same as" multiplying by its reciprocal and they would probably be reminded to convert mixed numerals to improper fractions. They would not be told why this procedure works nor how it relates to division with whole numbers. For the rest of class, the teacher would monitor students' work on these exercises. Then they would do 36, or 40, or 55 computations involving division of fractions. They might do a few story problems, although teachers often don't assign these because students find them frustrating.

Too rarely are procedures connected to their underlying conceptual foundations. And relating the topic at hand to other topics is not common. For instance, in this example, few teachers would help students understand that division of fractions is no different from division of whole numbers, that in both cases, the questions have to do with forming groups. Instead, mathematics tends to be presented in school in little airtight compartments, separated from one another in time and meaning. The school curriculum treats mathematics as a collection of discrete bits of procedural knowledge. This tendency to compartmentalize mathematical knowledge substantially increases what it takes to learn and to use mathematics. Each idea or procedure seems to be a separate case. Each requires a different rule, all of which must be individually memorized and recalled.

At the same time, traditional mathematics instruction makes little effort to relate mathematics to the learner, to help students engage in the questions and uses of the subject. Consequently, mathematics is not generally perceived as personally meaningful. Instead, it is something you do, a series of exercises that you complete. The teacher checks your work, marking errors. Often you are unsure whether you are right or not until you get your paper back.

All in all, this picture I am painting, one that is most likely a familiar one to you, helps to explain why many people who have "had" mathematics do not remember things that they were taught and, even more commonly, cannot make sense of situations, procedures, and answers involving quantities and space. (After all, the students who take the NAEP have *had* all that stuff on which they are being tested.) To quote the National Research Council report (1989), "a mathematics curriculum that emphasizes computation and rules is like a writing curriculum that emphasizes grammar and spelling; both put the cart before the horse" (p. 44). Graduates of this typical mathematics teaching cannot (or do not try to) invent strategies to make sense and they are likely to treat quantitative information as fact, exempt from critical examination and challenge. They rarely feel that they can assess the reasonableness of their own answers and are typically unsuccessful at applying procedures to solve problems. Many are left with feelings of inadequacy and anxiety about mathematics.

All this adds up to a system of exposing people to mathematics that is largely unsuccessful in empowering or inviting them to use or appreciate mathematics. How could we change these patterns of mathematical disenfranchisement? Clearly, we need to alter what goes on in mathematics classrooms. Students must develop sensible ways of dealing with quantity and space, using the tools of the domain in ways that they understand, that provide them with control over the reasonableness of their thinking. These tools include the concepts and procedures that have been developed over time by mathematicians; they also include processes of inventing, exploring, and justifying ways of making mathematical sense. The ability to perform arithmetical calculations simply will not suffice to equip today's (and tomorrow's) citizens. Instead, they must be able to sift and appraise statistical information, assess relative probabilities, estimate and predict, perceive and interpret patterns, and, in general, have a well developed sense of numbers, both large and small. To alter the portrait of mathematical illiteracy that we currently confront, the school and college curriculum will need to undergo radical revision. By curriculum, I mean here both what is taught and how it is taught.

To provide the reader with a picture of what this might look like, I turn next to a third-grade classroom[6]. The children in this class have been learning about numbers and about number theory--for example, about even and odd numbers, about positive and negative numbers, about multiples and factors, and about place value in the base-10 numeration system for recording numerals. On the day I describe they were investigating fractions as quantities and equivalent fractions as alternative representations of the same amount. The point of this story is to paint an alternative vision of mathematics teaching, a kind of teaching for understanding that aims to empower students to make sense of mathematics and to be able to reason with and about mathematical ideas themselves--precisely the kinds of capacities that the NAEP shows students are presently not developing.

Teaching Mathematics for Understanding--One View

Yesterday the class ended with one student, Jenny, asserting that ½ "is not a number." She backed up her claim, pointing at the number line that runs around at the top of the classroom walls, "See? Look at our number line. There's no ½ on there, just 2, 3, 4, and so on."

Because she wants the children to engage this assertion, the teacher decides to start class today by writing the following problem on the board:

> A man has 4 loaves of bread. He wants to share the bread equally among 8 of his friends. How much bread will he give each of his friends?

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[6]This story is based on my own teaching of mathematics during the 1988-89 school year. I teach mathematics daily, to a class of third graders in a local public elementary school. The students are diverse: Many speak English as a second language and they represent a substantial range of cultural, socioeconomic, and ethnic backgrounds.

The third graders copy the problem into spiral notebooks. One hears some of them consulting with one another: "You can't *do* it. There isn't enough," and "How many slices are in the loaves?" Several are drawing large loaves of bread in their notebooks and beginning to draw slices carefully in the bread.

The teacher walks around, looking at what the children are doing, and occasionally stoops over to ask a question, such as, "How much bread is each one going to get?"

After about 10 minutes, the teacher asks, "Does anyone need more time to work on this? How many are ready to discuss?"

A few raise their hands as they continue drawing smudgy lines carefully in their loaves of bread.

A few minutes later, the teacher opens the discussion of the problem. "Would someone like to show their solution?"

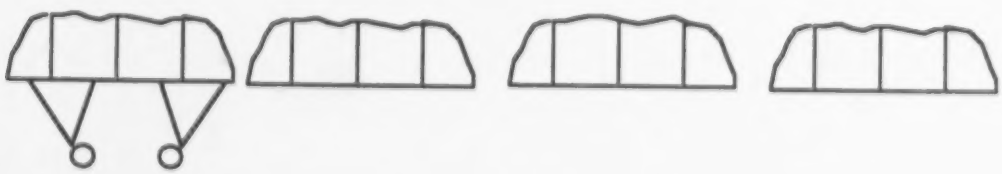
James volunteers eagerly, "But I'm not sure if this is right."

He draws four large loaves on the chalkboard and proceeds to divide each loaf into 8 slices. Turning to the class, he announces, "Each friend should get 4 slices."

Bridget's hand shoots up. "I challenge that. I think each friend gets 2 slices."

"Can you show that?" asks the teacher.

She draws four more loaves on the board and divides each into four slices. "You see? Two slices for each friend." She counts it out to prove she is right. "The first friend gets these two; the second these two, and so on."



"This is confusing," says the teacher. "How can James come up with 4 slices each and Bridget 2 slices for the *same* problem?"

"Bridget's slices are bigger," observes one boy.

Another child is wildly flapping his arm, trying to be recognized. "I just said that each friend could have ½ a loaf."

"Can you write that number?" asks the teacher.

He comes up and writes ½ on the board.

"And what amount of bread is James giving each friend?" asks the teacher.

There is a pause. She asks, "How much is one slice as James has cut it up?"

"One quarter?" proposes a small girl.

"Can you write that?" asks the teacher.

Over the next few minutes, the teacher, with her questions, guides the class to understand that each of James's slices is 1/8 of a loaf of bread because he has divided his loaf into 8 slices. The children write 1/8, 1/4, and 1/2, noting that the slices of bread that the different children have made are different sizes and that the slices that are 1/8 of the loaf are smaller than the slices that are 1/4.

"Doesn't that seem weird?" asks the teacher. "How can 1/8 be less than 1/4? 8 is greater than 4."

"That's *easy*," says Sharon. "1/8 is smaller because you have cut the loaf of bread into 8 pieces, not 4, so the pieces are smaller. That's why 1/8 is smaller than 1/4."

"What do the rest of you think about that?" asks the teacher.

"I agree with Sharon," says another girl. "If you cut a loaf of bread into 8 slices, of course, the slices will be smaller."

The class proceeds to write a number to represent each child's solution to the bread problem: 1/2, 2/4, 4/8. The teacher provokes the next problem with her next question: "Why do we have three different numbers for each of these?"

There is a brief moment of silence. Then several hands shoot into the air. One by one, different children give halting explanations--that "1 is half 2, 2 is half of 4, 4 is half of 8, so they're really all the same" or "they're all ways of saying "a half." One boy comes to the board and makes an elaborate explanation, using the drawings of loaves:

A lively discussion ensues, during which there is some confusion about the fact that 1/8 is less than 1/2, that 4/8 is not more than 1/2, and so on. The teacher orchestrates this discussion, asking people to speak up, monitoring who has the floor, asking for reactions from other students.

Gradually the children reach the conclusion that 2/4 and 4/8 are different ways of representing half a loaf of bread, that it depends on how many slices you make, but that four of the "skinny slices" (the eighths) are the same *amount* of bread as half the loaf, unsliced.

Near the end of class, the teacher asks the children if they can find the number on the number line that represents the number of loaves they started with. Several point to the 4. Then she asks if they can find the point on the number line that represents the amount of bread that each friend should get. Quite easily, someone uses the pointer to indicate a spot halfway between 0 and 1.

"That makes sense," he explains, "because it's more than 0 loaves but less than 1 whole loaf."

Just as class is ending, Erica raises her hand. "I noticed something. I think I have a conjecture," she says. "The reason that James's solution is 4/8 is because it's 1/8 from each loaf--1/8 + 1/8 + 1/8 + 1/8. You only have to add the 1's, not the 8's."

"Yeah!" exclaims one of the boys. " 'Cause if you added the 8's, you'd get a much bigger number! Umm . . . 4/32!"

"That's a very interesting conjecture," says the teacher. "Would you like to write that up and we can pursue it tomorrow? I'd like everyone to think about Erica's conjecture and see what you think. Does it make sense?"

* * *

Over the next few days the class solves and debates other problems like the loaf problem. They readily use drawings to convince themselves that 4/32 is a much smaller number than 4/8--in fact, that it represents the same amount of bread as 1/8.

Compare this lesson with one you remember or one that your own child has experienced in school. Typically, fractions are presented as something new, unrelated to the children's previous work with numbers. Using pictures of circles (sometimes pies or pizzas), the children learn ways of naming an answer to the question, "How much is shaded?" They may not be too sure where that question came from or why they would want to answer it (except on a workbook page). They may learn that the "top number" in a fraction is called the numerator, the "bottom number" the denominator. Often, to simplify things, children work first only with unit fractions (e.g., 1/3, 1/5), later with other proper fractions, still later

with mixed numbers and improper fractions. Equivalent fractions and computation with fractions are also separate topics. Discussion or debate about the ideas is rare.

What was going on in *this* lesson, described above? With their eye on the basic problem--dividing one number by a larger number--the students were employing mathematical ideas and tools in their work, in contexts that made sense to them: pictures, the number line, stories about sharing bread. At once, they were engaged in opportunities to learn mathematics and to learn to *do* mathematics. As far as mathematical content is concerned, the students used and developed their understandings of fractions, of equivalent fractions, and of the correspondence between numeral and number. All these learnings are important for equipping children with a comfortable sense of numbers--their meanings and notations.

But there was more mathematics in the lesson than that. The idea that mathematics entails puzzles and uncertainties and that mathematical thinking involves questions as much as answers was represented in the problem of knowing if Sharon's conjecture had exceptions to it. More than just getting right answers, doing mathematics in this classroom entails investigating, looking for patterns, framing and testing conjectures, arguing and proving. The search for patterns, formulating and testing their generalizability, are at the heart of the students' activity.

The process of presenting and justifying solutions provides fertile ground for inquiry and arguments as children search for reasonable solutions that their peers will accept. The challenges they present to one another reveal the nature and power of proof--how can one persuade others in one's community of discourse that one's conjecture is reasonable or true (Lampert, 1988)? These learnings are important as part of developing mathematical literacy, just as the ability to construct arguments, narrate events, or persuade, using written language, are part of written literacy. Neither knowledge of computational procedures nor knowledge of grammatical conventions alone is sufficient to equip learners with the power of literacy.

A significant feature of this classroom is that students are themselves sources of and validators of knowledge and insight. The teacher is not the only one who is able to determine if something makes sense. In this classroom students are helped to acquire the skills and understanding needed to judge the validity of mathematical ideas and results. These skills and understandings include specific knowledge--mathematical concepts and procedures; they also include the disposition to question and to examine mathematical claims and the confidence with which to do so. This matters; when mathematical answers are justified on the basis of the teacher's authority, learners may not develop the capacity to monitor the reasonableness of their thinking.

The teacher has a critical role to play in facilitating students' mathematical learning. She introduces a variety of representational systems (e.g., the drawing the children were

using in this lesson) which can be used to reason about mathematics; she models mathematical thinking and activity, and asks questions that push students to examine and articulate their ideas. However, perhaps most significant in the classroom context is the teacher's role in guiding the direction, balance, and rhythm of classroom discourse by deciding which points the group should pursue, which questions to play down, which issues to table for the moment, decisions which she makes based on her knowledge of mathematics as well as her knowledge of her students.

How Can We Get Mathematical Understanding?

What would it take to turn more mathematics classrooms into places where teachers could help students to acquire these kinds of skills and dispositions in mathematics, and where students were more likely to develop power and confidence with the tools of mathematics, more inclined to engage in and use mathematics? A very big question, this goes beyond the boundaries of this paper, for significant change in age-old patterns of teaching and learning have their roots in our culture and in the organizational patterns of schooling (see for example, Cohen, 1988). By no means unchangeable, these patterns demand serious consideration in their own right. In the pages that follow, I take up just one part of the question: What does a *teacher* need in order to orchestrate opportunities to learn mathematics with understanding, given the conception of understanding illustrated above? What does it takes to teach this or to teach like this?

Strategies for Change

The strategies for change focused on the teacher that are most often proposed include improving the materials that teachers have to use, training teachers in skills of effective teaching, and ensuring that teachers have adequate subject matter knowledge. Of the three, it is the third--teachers' knowledge of mathematics--that has been least well explored and defined. And the first two depend on it; alone, they cannot suffice to alter the patterns of traditional mathematics instruction.

Improve mathematics curriculum materials. Would it do to change the books that we use in mathematics classes? The presently available books focus on computational skills, omit other significant mathematics (such as geometry or probability), and represent math as recipe-following. In the state of California, where a curriculum framework for mathematics teaching was developed to alter fundamentally the nature of school mathematics teaching and learning, the committee charged with state textbook adoption rejected all textbooks that were currently on the market the first time they were reviewed. Since then, several major publishers worked hard to revise their textbooks in an effort to capture the lucrative California market. This struggle provides further evidence of how poor most available math curriculum materials are.

In any case, research on how teachers use textbooks suggests that providing better curriculum materials is necessary but is insufficient as a solution. Teachers, as professionals, adapt and shape the content and approaches embedded in text materials, omitting sections they feel are unnecessary, dropping problems they see as irrelevant or too hard, and adding things they perceive as important (Schwille et al., 1983). These decisions are shaped by their own understandings and beliefs. No textbook can determine what goes on beyond the classroom door; nor, I contend, should it.

Equip teachers with more effective techniques. General concerns with what goes on in schools have led many to advocate programs aimed at improving teachers' technical pedagogical skills. The popularity of Madeline Hunter is evidence for the widespread belief that the way to improve schools is to train teachers to deliver instruction according to clearly specified principles. Yet using "advance organizers" and "response cues" for students can smooth classroom interactions without affecting the substance of what students are taught. Teachers can clearly "explain" the steps of a mathematical procedure without any focus on its meaning. In short, a teacher can be fabulously efficient. Whether she can design opportunities for her students to engage meaningfully in mathematical activity is a different issue, dependent on other knowledge, skills, and commitments.

Ensure that teachers have adequate subject matter knowledge. Neither the perfect textbook lesson nor a smooth procedure for calling on kids will bail out the teacher who is confronted with a student who wants to know why, when he multiplies by a decimal, the answer is sometimes smaller (e.g., 4.06 x .5 = 2.03). Teachers must understand mathematics well themselves if they are to be able to respond to such a question--whether it is by directly answering or by reframing the question in a way that allows the student to figure it out himself. They should understand the subject in depth sufficient to be able to represent the subject appropriately and in multiple ways. They need to understand the subject flexibly enough so that they can interpret and appraise students' ideas, helping them to extend and formalize intuitive understandings and challenging incorrect notions.

This argument--that content knowledge matters--is often met with a story of some high school teacher who, although he had a Ph.D. in topographical analysis, was completely unable to help sophomores learn algebra. This teacher, the story goes, had "too much" subject matter knowledge. This paper argues that discussion about teachers' subject matter knowledge must turn from questions of "how much" to "what kind." More courses for teachers is *not* the solution, for college mathematics courses reflect the same patterns--if not worse--than those discussed above. Lecture, proof by coercion, and an emphasis on procedures, not meaning, permeate the pedagogy of higher education (Davis and Hersh, 1981; Kline, 1977). And instructors of undergraduate courses are often graduate students, not infrequently limited speakers of English. To dig into the question of "what kind" of subject matter knowledge teachers need in order to teach mathematics for understanding,

I will address four dimensions of subject matter understanding: knowledge of the substance of mathematics, knowledge about the nature and discourse of mathematics, knowledge about mathematics in culture and society, and the capacity for what I will call pedagogical reasoning about mathematics.

Substantive Knowledge of Mathematics

Hardly anyone would argue with the claim that teachers need substantive knowledge of mathematics--of particular concepts and procedures (rectangles, functions, and the multiplication of decimals, for example). Most would agree that teachers' understanding should be both "flexible" and "deep," two vague but nice-sounding descriptors. I propose instead three specific criteria for teachers' substantive knowledge: correctness, meaning, and connectedness.

Teachers' substantive knowledge of mathematics should certainly be *correct*. Teachers should know that rectangles are plane figures with four straight sides and four right angles and they should be able to correctly multiply 35.07 x .05. They should know that the places in our numeration system represent powers of 10, that division by zero is undefined, and they should be able to distinguish between a variable and an unknown. This, for many people, defines knowing the content. This is, after all, the main focus of most tests--for teachers or for kids. But "correctness" in mathematics is not always so straightforward. Are first graders *wrong*, for example, if they believe that zero is the smallest number and that 3 is the next number after 2? Elementary classrooms are filled with "truths" that ultimately are not--for example: Subtracting a larger number from a smaller one (i.e., 5 - 7) is impossible, you always get a smaller number when you divide and a larger number when you multiply, squares are not rectangles.

What is considered correct or incorrect depends on the domain, on the mathematical context in which people are operating. Ninth graders operating in the domain of rational numbers probably believe that there *is* no "smallest number" and no "next number" after 2. Does this make first graders *wrong* if they believe that 3 comes after 2? And then what happens if a pupil makes an assertion that presses on the boundaries of the current domain? Suppose a first grader claims that *2½* is the next number after 2? Epistemological dilemmas such as this one arise in everyday teaching; figuring out how to deal with them is central to teaching mathematics for understanding.

But correctness is not the only criterion. Teachers should not just be able to "do" mathematics; if they are to teach for understanding, they must also have a sense for the *mathematical meanings* underlying the concepts and procedures. Many children and adults go through mathematical motions correctly without *ever* understanding what they are doing or why. It is one thing to be able to get 3½ as an answer to 1 3/4 + ½; understanding the referent for the 3½ entails knowing what it *means* to divide by ½. Similarly, it is one thing

to line up the numbers correctly on each line of the computation for a long multiplication problem, it is quite another to know *why* you are doing that.

Explanations of mathematics entail more than repeating the words of mathematical procedures or definitions. The statement, for example, that you "carry the 1" is not a mathematical explanation of regrouping in addition; neither, by itself is the statement "7 + 0 is undefined." To explain mathematics is to focus on the meaning, on the underlying ideas and concepts. To explain is to say *why*, to justify the logic, or to identify a convention.

Finally, however well explained or correct, mathematical knowledge is not a collection of disparate facts and procedures. The meaning of division of fractions can be *connected* to what it means to divide, for instance. Connections exist at multiple levels between and among ideas. Smaller ideas belong to various families of larger concepts; for example, decimals are related to fractions as well as to base 10 numeration and place value. Topics are connected to others of equivalent size; addition, for instance, is fundamentally connected to multiplication. Elementary mathematics links to more abstract content--algebra is a first cousin of arithmetic, and the measurement of irregular shapes is akin to integration in calculus. Mathematical ideas can be linked in numerous ways; no one right structure or map exists.

Despite this, mathematics is often delivered in school in small isolated packages. This makes it much harder to learn for there is so much more that must be remembered. In addition, treating mathematics as a collection of separate facts and procedures also seriously misrepresents the logic and nature of the discipline to students. If teachers are to break away from this common approach to teaching and learning mathematics and teach for understanding instead, they must have connected rather than compartmentalized knowledge of mathematics themselves.

The Nature and Discourse of Mathematics

A second component of subject matter knowledge consists of what I call knowledge about the nature and discourse of mathematics. Concretely: In the example of teaching for understanding above, students were engaged in arguing about alternative mathematical hypotheses. They knew that their answers were subject to the scrutiny of their classmates as well as of their teacher. They understood that part of doing mathematics entails looking for patterns, trying to reach generalizations, challenging old assumptions, and formulating new ideas. These students' experience with mathematics is different from the usual. Typically, students experience mathematics as a series of rules to be memorized and followed, as a domain of clearly right and wrong answers (which are distinguished by the authority of the answer key), as a silent and private activity involving mostly calculation. Speed and accuracy are what count; justification and reasonableness play little role.

"So what?" one might ask. Perhaps the first is a fairer representation of mathematics, but, some would argue, many students aren't going to be mathematicians, after all, and the goal for now is proficiency. On one hand, however, it is not for us to decide who will one day want to pursue mathematics. On the other hand, even proficiency is facilitated by helping students acquire control and power in the domain. When the answers seem arbitrary, when they reside in the teacher's head or in some book, when mathematics is a step-by-step routine, students are not likely to feel any sense of competence. Engaging students in mathematics, much as we already aim for genuine engagement in literature or writing, holds promise for the outcomes of formal mathematical study.

What do teachers need to know about the nature and discourse of mathematics? Do teachers need to become philosophers of mathematics? Again, the point is not how *much* but what *kind* of knowledge teachers need. I propose three aspects of understanding: one focused on answers, justification, and authority; another on mathematical activity; and another focused on the basis of mathematical knowledge--convention versus logic.

First, teachers need to consider what counts as an "answer" in mathematics. Typically, the question, "Is 124 even or odd?" is answered in classrooms with one word: "Even." Yet, to consider "even" an answer is to give short shrift to justification and to mathematical meaning. In mathematical discourse, justification is as much a part of the answer as is the answer itself. "Even, because half of 124 is 62 and even numbers are numbers that can be divided evenly in half," or "Even, because 123 is odd and 125 is odd and the pattern goes even-odd-even-odd," or, "Even, because 100 is even, 20 is even, and 4 is even," are all possible alternative answers that contain a justification to establish the truth of the answer. Important to note here is that mathematical explanations necessarily rely on earlier assumptions or already established ideas (e.g., that even numbers are whole numbers that are divisible by 2 and that divisibility implies a whole-number quotient--that is, that $3 \div 2 = 1\frac{1}{2}$ does not make 3 divisible by 2).

How the truth or reasonableness of an answer is established in mathematics is a closely related issue. Typically, students know if their answers are right if they match those given in the back of the book or keyed in the teacher's guide or if the teacher says they are. In the discipline of mathematics, answers are accepted as true when others in the community, who share similar assumptions and core understandings, are unable to come up with viable counterevidence or refutations. Mathematicians do not look their conclusions up in books to see if they got them right. Instead, they provide mathematical arguments designed to persuade others of their conclusions.

Classroom discourse aimed at emulating these patterns of discourse involves children in proposing solutions which (as described above) contain justifications that are subject to the scrutiny of the rest of the class. Suppose a student claims, for instance, that "115 is even because half of 100 is 50, half of 10 is 5, and half of 5 is $2\frac{1}{2}$--so half of 115 is $57\frac{1}{2}$." Instead

of the teacher pronouncing this incorrect, other students can examine the claim and challenge it by pointing out that the requirement that an even number be divisible by 2 means that the result must be a whole number--thus 5 (and, hence, 115) is *not* even. Authority for reasonableness need not rest solely with the teacher. In making justification the basis for correctness, students gain control in mathematics--a control that can afford them competence, confidence, and enjoyment. And, in everyday life, there are no answer keys: Students must develop the capacity to assess the reasonableness of their own solutions.

A second aspect of mathematics that teachers need to consider explicitly is what "doing mathematics" entails. What do mathematicians do? Despite what generations of children have done in school in the name of mathematics, figuring columns of sums or performing long division is, at best, a pale shadow of "doing mathematics." Instead, mathematics consists of activities such as examining patterns, formulating and testing generalizations, constructing proofs. The procedures one learns in school were generated as part of that activity and are now part of the accepted arsenal of mathematical tools. Becoming familiar with these tools is a critical part of learning mathematics; using them in the context of mathematical activity affords them a more appropriate importance than when they *become* the point, as is too often the case.

Finally, mathematical knowledge is based on both convention and logic. This has implications for what can be derived logically (based, of course, on prior assumptions or previously established ideas) versus what could (at this point) be reasonably defined or handled in an alternative way and is, therefore, somewhat arbitrary. For teachers, distinguishing between the two is critical. For example, that our numeration system is based on tens is arbitrary--we could just as well use a base 5 or base 12 system. That we use a procedure that involves crossing out tens and "borrowing," or regrouping, in order to subtract, is also a convention.

Other reasonable subtraction procedures can be (and have been) invented. However, that "you can't subtract up" in a subtraction problem

$$\begin{array}{r} 5\,6 \\ -\,2\,9 \\ \hline \end{array}$$

is *not* merely convention if we agree that subtraction is not commutative: 6 - 9 is not equal to 9 - 6. This distinction is important with respect to the question of authority and its relationship to learning mathematics. Children can establish for themselves, for example, that if they "subtract up" they will obtain

$$\begin{array}{r} 5\,6 \\ -\,2\,9 \\ \hline 3\,3 \end{array}$$

a result that will not correspond to what they get when they take 29 objects away from 56.

"Invert and multiply" is also erroneously perceived to be an arbitrary convention of procedure. However, multiplication and division are *logically* reciprocal: 6 ÷ 2 produces the same result as 6 x ½, for example. Confronted with 6 ÷ ½, and considering what it means to divide, students can figure out that this is asking how many *halves* there are in 6. Since there are two halves in each whole, then there will be 6 x 2, or 12, halves altogether in 6. When teachers confuse knowledge based on convention with knowledge that is logically derivable, the nature of mathematics becomes muddled.

Rules are made about ideas or procedures that can be figured out logically (e.g., "division by 0 is undefined; 0/0 is considered indeterminate" or "when you multiply by 10, just add a zero"). And sometimes students are asked to figure out things that are purely arbitrary, given the point they are in their own mathematical development (e.g., that 1 is not classified as a prime[7]). The major issue here is for teachers to realize how much of what pupils learn *is* derivable and logical, not arbitrary and conventional. When students can derive and justify ideas mathematically, they are better equipped to access the underlying meanings and less likely to conceive of particular mathematical ideas as "something you just have to remember."

Knowledge About Mathematics in Culture and Society

If teachers are to play a role in reversing the patterns I described at the beginning of this paper, then they need additional knowledge of mathematics, knowledge that is more contextual than disciplinary. They need to understand, at least broadly, the role played by mathematics in our society and in everyday life, about the evolution of mathematics as a field of human inquiry, and about the achievement and participation problems that plague school mathematics. Nothing is more often trivialized in school than so-called "applications" of mathematics. Students are asked to calculate amounts that no one would ever calculate--exactly or at all--in everyday life, and, in general, to use mathematics in ways that misrepresent its uses and applications. Who, for example, after he cooks breakfast, subtracts the number of eggs cooked from the original number of eggs in order to figure out how many eggs are left? Wouldn't most people simply count the eggs remaining? Probability has applications that go beyond coin tossing. Measurement is critical in many familiar undertakings; graphing relationships a useful tool in making decisions.

Applying mathematics to real situations also involves framing a problem to which mathematics can contribute--figuring out a question, setting the constraints, deciding on the precision needed. Would an estimate suffice? What order of magnitude matters? For

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[7]If primes are the numbers whose only factors are 1 and themselves, then 1 appears to be prime. If, however, all numbers can be expressed uniquely as the product of primes--the fundamental theorem of arithmetic--then the set of primes cannot include 1 (otherwise this theorem does not hold for 6 could be expressed as 2 x 3 x 1 or 2 x 3 x 1 x 1 or 2 x 3 and so on. This dilemma illustrates the systemic interrelatedness of ideas in the territories of mathematical knowledge.

example, trying to figure out how much to charge for handmade stationery involves deciding on a desirable profit margin, estimating total costs, assessing the market, and so on. If teachers are to help students learn mathematics in ways that allow them to make connections to everyday life, they themselves must know more about mathematical connections and applications. They need to have an awareness of how mathematics is used in a wide variety of settings and endeavors--including uses that are recreational and intellectual as well as practical. Just as we want students to read because reading is inherently worthwhile, so should mathematical play and intellectual inquiry be legitimate goals of mathematics education.

Teachers also need some awareness of the evolution of mathematical ideas across history and in different cultures. In teaching numeration, for instance, it may be useful to understand that human beings have sought and constructed a wide variety of systems of counting and recording quantities, of which our base ten positional system is one. How are Roman numerals different as a system? Zero, as a numeral to represent nothing, was a later invention. Knowing about the Mayans and why zero became important to them is useful both in understanding positional numeration[8] as well as in helping students see and value that many peoples have contributed to the development of mathematics.

This year, in my own class, I used the Egyptian invention of fractions to provide a real context for developing an understanding of rational numbers. My third graders were actually facing some of the same puzzlements confronted by others over three thousand years ago--how to distinguish between slices of bread from a loaf that has been cut into eight slices and slices from an identical loaf that has been cut into four slices. In each case you can say that you have *one slice*, but the amounts of bread are clearly different. In developing ideas about eighths and fourths, these eight-year-olds not only learned to write 1/8 and 1/4 to correctly represent the quantities, but they could also explain clearly that 1/8 was obviously *less than* 1/4. Connecting what students learn and how they learn it to the historical development of mathematics connects them in a fundamental way to the growth of knowledge as a constructive process of continual invention and revision. Furthermore, when teachers know about the alternative ways in which different peoples have worked with notions of quantity and space, they can use that knowledge to enhance students' sense of pride in their heritage.

Finally, mathematics is a key filter in U.S. secondary schools and, thus, a critical determinant of students' futures. While some students take four years of math in high school, often through calculus, many others drop out formally after the ninth grade. Of those who elect to end their study of mathematics, many have dropped out in spirit years earlier, while still in elementary school. They have come to see themselves as bad at math,

[8]A *positional numeration system* is one in which the position of a numeral also determines its value--e.g., the 3 in 39 is worth more than the 3 in 53. Contrast this with the Roman numeration system that is not fundamentally positional--e.g., X is consistently worth 10. Zero is important in a positional system--for instance, to mark a difference between 1 and 10.

as not mathematically inclined. They aspire to futures that do not require mathematics. The fact that these students are also disproportionately black, Hispanic, and female, is a serious issue.

If teachers are to alter this pattern, they need to be aware of factors that contribute to it: the patterns of interaction in classrooms, the cultural stereotyping of "math types," the sources and power of encouragement or discouragement to study mathematics, the kinds of applications that predominate in math texts and math classrooms, linguistic differences, and difference in basic cultural assumptions or understandings, for example. A good example of the last factor was told to me by my colleague Bill McDiarmid, based on his experience with Yup'ik Eskimo children in western Alaska. In this culture, dividing a catch or a kill equally means that each hunter's share is based on his or her *need*. Conceiving of "equal" portions in the mathematical sense--as portions that are the same in quantity--was at odds with cultural assumptions. This does not imply that Yup'ik children should not learn the mathematical concept of "equal," but a teacher who is aware of this different basic understanding would be able to approach it with sensitivity, offering the mathematical concept as a different way of thinking about "equal" in another context, for instance.

Pedagogical Reasoning in Teaching Mathematics

So far, this paper has addressed some of the kinds of knowledge about mathematics that teachers need in order to teach mathematics for understanding. I have outlined various aspects of mathematics that teachers should understand. Unlike some current arguments, however, I have not proposed that teachers should have a repertoire of representations--of examples, explanations, activities--that they can use to teach mathematics. While I do think such a repertoire is essential, I chose for this paper to focus on what teachers need to know about the *subject matter* of mathematics. Partly this is because I think that this question typically gets little or superficial consideration, partly it is because teaching is dynamic. Teachers, from moment to moment, ask and answer questions, interpret students' understandings, provide illustrations or analogies, decide to drop or add examples from the text, make decisions to follow or drop a tangent, and so on. If we want teachers who can, in the thick of things, manage the mathematics of their classrooms in ways that allow students to learn with understanding, we need to pay close attention to what teachers know and how they draw upon that knowledge in this dynamic.

Teachers' everyday work consists of activities as various as choosing a worksheet, using the teacher's guide to plan a lesson, responding to a student's question, examining students' written work, developing an example or explanation, assessing what students understand. Take developing an example or explanation. Suppose that you are teaching fifth grade and you want to help students understand multiplication of decimals. When you were taught, you remember that your fifth-grade teacher told you to forget about the decimal points and just multiply the numbers as though they were whole numbers:

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4.06      ----->      406
x .5                  x 5
                      2030
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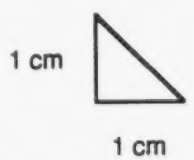
Then count the number of decimal places in the original problem and place the decimal point that many spaces over in your answer: 2.030. Now, you could just use this explanation as is, but you have a sense that it doesn't focus on the underlying meaning. Why does that work to add up the number of decimal places? And what does 4.06 x .5 mean? What could you do? Your substantive knowledge--what you understand about multiplication and about decimals--will shape what you come up with. A teacher who is trying to teach for understanding should know more than that the answer is 2.030.

Take the common task of planning a lesson from a textbook. Teachers should be both able and inclined to appraise the adequacy of a textbook's presentation of multiplication of decimals. Does it emphasize rules and steps over the meaning of the operation? How appropriate are the activities it suggests in terms of engaging kids in genuine discussion? Does it show any connection between the multiplication of decimals and any context in which this might come up--and, if so, is the context sensible or silly? Appraising and modifying textbook lessons depend on the teacher's own understanding of the content.

Students ask questions all the time in classrooms: "Is zero even or odd?" "When you multiply 4.06 x .5, why is the answer smaller?" They make claims: "Zero is a multiple of 5." "I have a new way to do this problem." "This triangle has a perimeter of 3 centimeters."



Deciding how to respond to students' questions, claims, puzzlements is a decision that has important consequences for what students learn both about the substance and the nature of mathematics. Should the teacher respond--and if so, with a question, with an explanation, or with a suggestion that the comment be put aside for the moment? And, if the decision is to respond, what should the teacher do or say? Perhaps the comment should be opened up to the class. While there is no single best course of action, these are crucial questions.

Teaching for understanding entails keeping a wide range of considerations in mind: about the substance of the content, about the ways in which the nature and discourse of mathematics are represented, and about social and cultural aspects of mathematics. Teachers' capacity and inclination to weave together these different considerations is a critical part of teaching mathematics for understanding, one that goes beyond simply knowing or being aware of certain things. We need to concern ourselves with the extent to which mathematical considerations

affect teachers' pedagogical reasoning. For example, it may be helpful to tell second graders who are learning to subtract with regrouping ("borrow") that "you can't subtract a larger number from a smaller one."

However, a teacher who neither sees nor cares that he is passing on an ultimately false idea seems to fail to consider the consequences for his students' later learning. There is no right answer to these dilemmas in teaching; teachers must make those judgments themselves. However, concerns for making the content "fun" or "easy" for students often overshadow mathematical considerations. In the example given above, it matters little if the teacher is aware of negative numbers if he does not at least weigh that as one consideration in his decision about how to teach second graders to "borrow." It also matters little if he knows one or more excellent concrete models for subtraction with regrouping. Instead, what matters is the extent to which he is disposed to consider mathematics in choosing pedagogical courses of action.

Conclusion

Although something called "subject matter knowledge" is widely acknowledged as a central component of what mathematics teachers need to know, little agreement exists about what this means or how to tell if teachers have "it." Course work, grades, test scores are the most frequent surrogates for subject matter understanding. These surrogates result in a superficial definition of subject matter knowledge, one that focuses exclusively, at best (and probably, in fact, don't), on the correctness of teachers' substantive knowledge. This paper links the argument about what teachers need to know about mathematics to current concerns for improving the teaching and learning of mathematics. Hopes for interrupting the vicious cycle in mathematics education and altering the outcomes of school mathematics teaching depend, at least in part, on a closer and more serious consideration of the mathematics that teachers need to understand, as well as how, when, and where they can acquire this kind of understanding and how we can assess that understanding.

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PREPARING ELEMENTARY TEACHERS TO TEACH MATHEMATICS

E. Ray Phillips and A. Edward Uprichard[9]

A broad liberal arts education is essential for prospective elementary school teachers. An appreciation for how the human race and society have progressed to the present and a well founded philosophical notion of what the future should be lay the foundation for guiding the development of young children through schooling. The understanding needed for meaningful elementary school instruction in the basic disciplines such as science, mathematics, languages, and social sciences cannot be gained through introductory and survey courses as currently structured and taught. There is considerable agreement among educators and professional organizations that significant changes in teacher education programs (liberal arts and professional curricula) must occur if they are to produce teachers with the mathematical skills and knowledge needed in schools of the year 2000 and beyond (The Carnegie Task Force on Teaching, 1986; Holmes Group, 1986; James and Kurtz, 1985; National Council of Teachers of Mathematics, 1981, 1987; Price and Gawronski, 1981).

In order to propose an answer to the question, What do teachers need to know to teach elementary school mathematics? the following four major areas will be discussed: (a) What is mathematics? (b) What mathematics ought be taught in elementary schools?, (c) How should teachers teach mathematics in elementary schools? and (d) What kind of teacher education program is needed to prepare elementary teachers to teach mathematics?

What Is Mathematics?

Mathematics is unique among the sciences. While referred to historically as the "queen of the sciences" and "the language of science," mathematics is a man-made abstract discipline which has as many differences as similarities with the other sciences. The nature of mathematics and mathematical thought make it a complex discipline which is difficult to define. Oftentimes, teachers hold a monolithic view of mathematics. Many secondary mathematics teachers think of mathematics as abstract deduction involving considerable symbolism, definitions, theorems, and proof making with little or no relationship to the real world. In contrast, many elementary teachers equate mathematics with arithmetic which focuses on computational skills such as addition, subtraction, multiplication, and division with whole numbers, fractions, and decimals (Reys, Suydam, and Lindquist, 1989). In order to facilitate students' understanding and appreciation of mathematics and to motivate students

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to study mathematics, teachers must broaden their perspectives on "What is mathematics?" (Spector and Phillips, 1989).

To build the philosophical and pedagogical rationale for what teachers need to teach mathematics, the "nature" of mathematics will be discussed as opposed to a precise "definition" of mathematics. Mathematics is not just a set of rules to be memorized and algorithmically applied to routine exercises found in textbooks (Phillips and Keese, 1987). Mathematics is a human endeavor and, as such, it is alive and constantly changing (Smith, 1987). Mathematics is a set of related ideas, a way of thinking. It is something to be appreciated as an art just like painting, poetry or music, and to be used as a tool. To do mathematics, to experience or become involved in mathematical thought involves a dialogue or discourse grounded in inquiry that focuses on exploring, observing, describing, interpreting, questioning, conjecturing, justifying, and predicting. This dialogue or discourse occurs between the learner and himself or herself and with others. The dialogue is stimulated by the structure of the discipline, the needs of the learner and/or societal needs, and is represented by models, diagrams, symbols, and language. A major goal of mathematics instruction is to help each learner to engage in this dialogue (mathematical thinking) to the extent his or her ability allows.

More specifically, the authors believe the following perspectives of mathematics are important for the elementary teacher.

1. **Mathematics Is *a Way of Thinking.***

Solving many textbook and real-world problems requires organizing, describing, analyzing, and interpreting data. Consider the following examples.

> ***Example A***
> At Susan's birthday party, the first time the doorbell rings 1 guest enters. On the second ring 3 guests enter. On the third ring 5 guests enter, and so on. How many guests will enter on the sixth ring and how many guests will be present after the sixth ring?
>
> Solution: Organize the data in a table.

Ring No.	No. guests entering	Total present
1	1	1
2	3	4
3	5	9
4	7	16
5	9	25
6	11	36

Example B

A factory in Maine makes and sells sheepskin coats. The cost of manufacturing each coat is m dollars for material and l dollars for labor. If the selling price of each coat is s dollars, what is the profit?

Solution: Write a mathematical equation.

$P = s - (m+l)$

Where P represents the profit.

Example C

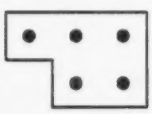
Is the sum of two odd numbers an odd number?

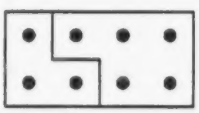
Solution: Draw a model.

Odds look like this 3

Evens look like this 4

3 + 5 = 8





The sum of two odd numbers will always be an even number.

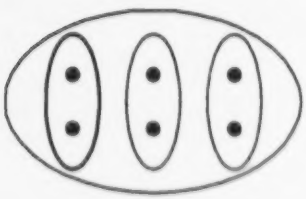
Note the power mathematics provides in the thinking process through equations, models, charts, tables, etc.

2. Mathematics Is a *Study of Related Ideas and Patterns*

There are many patterns that occur in mathematics and many relationships between and among mathematical ideas that exist. This helps to bring structure to the discipline. The system of related ideas dictates a hierarchical approach to the teaching and learning of mathematics since many new topics are intricately related to and build upon previously developed ideas. For example, the basic fact 8 + 4 = 12 is related to and facilitates the development of the basic fact 12 - 4 = 8. It is important for children to understand the

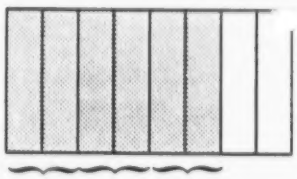
relationships among the basic operation of addition, subtraction, multiplication and division. For example, if students understand the meaning of the operation of division on whole numbers, then division on the set of rational numbers will become an understandable natural extension (see diagram).

6 + 2 means
separate a
set of 6 into
sets of 2 each.



There are 3 sets of 2
in a set of 6.
Therefore, 6 + 2 = 3.

6/8 + 2/8 means
separate a set
of 6/8 into sets
of 2/8 each.



There are 3 sets of 2/8
in a set of 6/8.
Therefore, 6/8 + 2/8 = 3.

3. Mathematics Is *a Language.*

Mathematical language utilizes highly technical terms and specialized symbols. While the structure of this language differs significantly from ordinary English, it facilitates communication of mathematical ideas and relationships as well as scientific and real-world situations (Phillips, 1977). Obviously, mathematical proficiency requires the ability to translate from English to mathematics and vice versa. Translation of the sentence "Six times two less than a number is twelve" into the mathematical sentence "6(n-2) = 12" makes finding the number for which this statement is true simple.

Mathematics as a language allows generalization from the concrete to the abstract. Consider the following situation: "On a trip to the mountains, a family left home at 8 o'clock and traveled 10 hours. What time did they arrive at the mountains?" Students quickly discover that just adding the 10 hours traveled to the time they left (8 o'clock) will not give the arrival time since there is no 18 on the clock. Further, with guidance they will discover that it is necessary to subtract 12 from 18 (or divide 18 by 12) to get the arrival time (6 o'clock). This specific example translates as $8 + 10 = 18 = 12(1) + 6 \equiv 6$. With mathematical language, the abstract generalization $t + h = s = 12q + r \equiv r$, which describes all similar situations, follows.

4. Mathematics Is *an Art.*

Mathematics is characterized by patterns, order, and consistency. Unfortunately, many students view mathematics as a set of unrelated tricks that must be rotely memorized and applied to exercises exactly as the teacher has demonstrated. Through meaningful instruction and guidance most children can understand and appreciate the underlying consistency, structure, and orderliness of mathematics--its beauty. For example, choose a whole number between 1 and 10 (7). Add the number that comes one before the number picked (6) to the number that comes one after the number picked (8). Divide by 2. What do you get?--7. Interesting!

5. Mathematics Is *a Tool.*

Many aspects of everyday affairs are affected by mathematics from the mundane chore of balancing a checkbook to the technological feat of landing a spacecraft on the moon. Children must see and appreciate the many applications of mathematics to their world. Its utility is what makes most children see the importance of mathematics and, thus, the need to learn mathematics.

Mathematics involves both inductive and deductive reasoning. Based upon reasonable assumptions and definitions, relationships are demonstrated as logical consequences of previously developed truthhoods. Note that this *deductive* procedure is a man-made thought process. While mathematics and science share many similarities in their goals and expected outcomes of the enterprise of science, there are basic differences which set mathematics aside from the other sciences. Mathematics and science are both concerned with the verification and extension of knowledge. However, mathematics is creative in nature and science is more descriptive in nature; that is, mathematicians create ideas and demonstrate truthhoods about these ideas using thought processes. Scientists attempt to describe existing phenomena and demonstrate truthhoods about these phenomena through experimental and nonexperimental procedures. Of course, mathematics provides many mathematical models for describing natural phenomena and statistical procedures for demonstrating acceptable levels of truthhood about these phenomena. And many of the relationships existing among the phenomena can be stated with mathematical equations.

Mathematicians also observe phenomena and formulate conjectures based upon these observations. Some of these *inductively* derived conjectures may be shown deductively to be false and many are proven. Some of these conjectures are neither verified nor refuted and remain as historically interesting and puzzling problems for future students of mathematics. This informal, inductive and intuitive process is essential in the generation of testable hypotheses and the development of new ideas. These inductive, informal activities lead young children to a better understanding of the nature of mathematics and an appreciation of the beauty of mathematics (Baroody, 1987; Furth, 1969; Piaget, 1928). While both

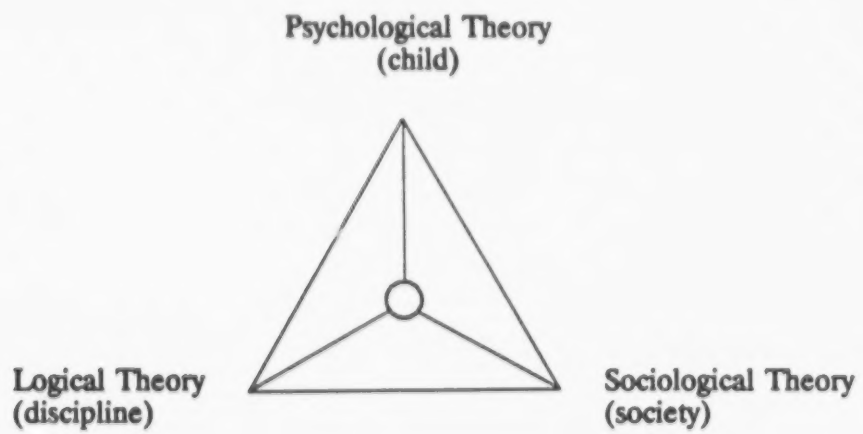
induction and deduction are utilized in the process of mathematics and mathematical thought, mathematics courses completed by prospective elementary teachers usually emphasize only the deductive nature of mathematics.

What Mathematics Ought Be Taught in Elementary Schools?

Mathematics is a major component of the elementary school curriculum. A large proportion of the instructional time is devoted to communication (reading, writing, speaking, listening) and mathematics (Suydam and Osborne, 1977). Future student success in school is highly dependent upon mathematical and reading skills developed in the elementary grades. Unfortunately, just as there is no national school system in the United States (state and local school districts are somewhat independent) there is no standard national curriculum guide for elementary school mathematics. However, there is considerable agreement among educators and professional organizations about what mathematics is appropriate for elementary school children, and the content of most elementary school textbook series is very similar. Many state and local school districts have developed their own curriculum guides. To no one's surprise, these guides closely parallel the content presented in the major elementary school textbook series.

Three major factors influence the elementary school mathematics curriculum. What mathematics is taught, when it is taught, and to a large extent how it is taught is determined by the nature of mathematics (discipline), how children develop and learn (child), and by what is believed to be useful and necessary in today's world (society).

Glennon and Cruikshank (1981) discussed these influencing factors in terms of logical, psychological, and sociological curriculum theories.



A brief, simple explanation of these theories is given below.

> *Logical Theory* suggests that the structure essential to the facilitation of teaching, learning, retention, and problem solving resides in the discipline itself (mathematics--discipline centered).
>
> *Psychological Theory* suggests that the curriculum result from the immediate needs or expressed needs of the learner (learner--child centered).
>
> *Sociological Theory* suggests applied or socially useful content--content that is needed for proficiency or competency in real-life (utility--society centered).

The curriculum for the "average" student might be represented by the intersection of the bisectors of the vertex angles of the curriculum triangle where equal emphasis is given to developing both an understanding of the nature of mathematics and functional mathematical skills while taking into consideration the needs of the student. Depending upon the students and the objectives to be achieved, emphasis might shift off-center towards one of the vertices. However, the content to be covered is essentially the same. The change is in the approach to teaching and to the extent given topics are covered. (How teachers should teach mathematics is covered in the next section.)

Many other factors influence the elementary school mathematics curriculum. These include research, technology, economy, testing, educational agencies (state, local and federal), and textbook publishers. Of course, professional educational organizations such as the National Council of Teachers of Mathematics (NCTM), the National Council of Supervisors of Mathematics (NCSM), the Mathematical Association of America, the Conference Board of the Mathematical Sciences and others have played a major role in establishing guidelines for the content of elementary school mathematics. The National Council of Supervisors of Mathematics (NCSM, 1977) argued that elementary school children need more than basic computational skills and identified ten basic skill areas. The NCSM (1988) has further extended and expanded their concept of basic skills areas to the twelve components of essential mathematics. The NCTM Commission on Standards for School Mathematics (1987) has developed 50 standards grouped into grades K-4, 5-8, and 9-12. Major textbook series and state and local curriculum guides are written with these components in mind.

What mathematics ought children learn? Some might argue that this question is difficult to answer because we do not know what specific skills and knowledge will be most useful to children in the future. However, an examination of current elementary textbook series indicates a general consensus regarding what mathematics should be taught in elementary schools. Certainly, the textbook determines to large extent what mathematics is taught in the elementary school classroom. While the emphasis on understanding,

problem solving, the language of mathematics, applications, estimation, enrichment topics and reinforcement vary somewhat from series to series, the basic content covered and the sequencing of the topics is essentially the same. In general, these topics are number and numeration, operations/algorithms on whole numbers and rationals, number theory, measurement, geometry, probability and statistics, and using the calculator and computer.

There does seem to be an accepted answer to the question, "What mathematics ought be taught in elementary schools?" However, how we should teach mathematics in elementary schools is open to question. Clearly, schools are not preparing students with the mathematical proficiency needed to meet the challenges presented by the technological world of today and tomorrow (Dossey, Mullis, Lindquist, and Chambers, 1988).

How Should Teachers Teach Mathematics in Elementary School?

How should mathematics be taught in elementary school? The answer to this question seems obvious. Teachers should teach for meaning and understanding. Based upon student performance, it appears that such teaching is not occurring (Dossey, Mullis, Lindquist, and Chambers, 1988). Thus, the questions that need to be answered are (a) How can teachers help children learn mathematics meaningfully instead of rotely? and (b) How can elementary teachers be prepared to meet this challenge?

Clearly, mathematics is a discipline students must experience and do in order to learn. That is, they must engage in mathematical thought and problem solving. There must be direct teacher/student interaction through systematic questioning as students create their own mathematics (Uprichard, Phillips, and Soriano, 1984). Therefore, the efficacy of the lecture-and-listen format or the distribute-and-collect (work sheets) format must be questioned. In its latest report, The National Research Council (1989) reports, "Evidence from many sources shows that the least effective mode for mathematics learning is the one that prevails in most of America's classrooms: lecturing and listening" (p. 57). These instructional techniques encourage rote memorization and tend to turn students off to mathematics.

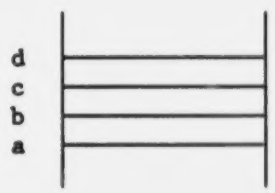
According to Ausubel (1968) two conditions must be met for meaningful learning to occur. First, the subject or topic or concept must be inherently meaningful. If the task to be learned in meaningless, you cannot make it meaningful. What is 4 x 8? If the student forgets or doesn't recall the fact immediately, he can determine the product because the concept of multiplication is meaningful. 4 x 8 means 4 sets with 8 in each set. The student can produce a mental image of the situation, draw a diagram, or build a physical model. On the other hand, if the student forgets his telephone number or zip code he cannot "figure it out" or determine it because these tasks are meaningless.

Secondly, the student must have a background of previous learning to which the new learning can be related; that is, the new task must be "hooked on" to the learner's existing

ideas to be meaningful. In this case, multiplication is defined as repeated addition which the child has already learned. Thus, 4 x 8= 8+8+8+8. The concept of multiplication is meaningful and it is related to addition which already exist in the child's cognitive structures. Therefore, basic facts can be learned meaningfully, and if recall becomes a problem, the child can reconstruct the notion of *x* sets with *y* in each through models. Of course, to enhance the meaningfulness of concepts and to facilitate retention and recall, the new learning should be applied and practiced.

In teaching mathematics, teachers must consider Piaget's theory of cognitive development (learning is a function of development). Some learning tasks are inappropriate at certain stages of the child's development. In addition, teachers must recognize that mathematics is highly structured and hierarchical in nature. Thus, Gagné's hierarchical theory of learning (development is a function of learning) must be considered in conjunction with Piaget's developmental theory.

At the risk of oversimplification, consider the four tasks a, b, c, d to be learned:



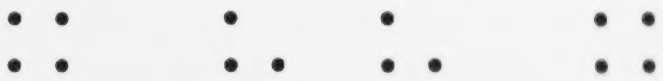
Learning Ladder

There must be a "cognitive fit" between the nature of the tasks to be learned and the child's developmental stage; that is, students' must be ready to learn in terms of cognitive prerequisites (Piaget). For instance, we would have difficulty developing the commutative property of addition with very young children (4+3 = 3+4) unless they were at the cognitive stage necessary for conservation and reversibility. Some students may be able to build and/or visualize models for 4 • • and 3 • and still not see that
• • • •

4 + 3 = 7

• • • • • •
• • • • • • •

Seeing that 4 + 3 = 3 + 4 is even more

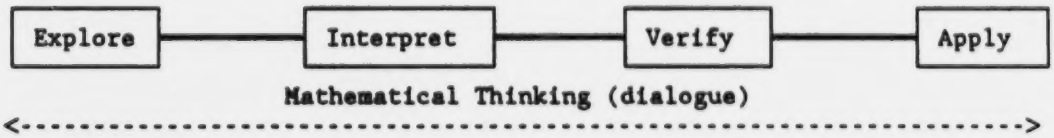


difficult because the configuration of the models for 7 differ. If the dots are rearranged as shown below, many young children will still not recognize both as models for 7.

Clearly, certain cognitive prerequisites must be in place before certain new learnings can occur.

Assuming that there is a "cognitive fit" between the nature of the tasks to be learned and the child's cognitive development, there is prior learning necessary for task "a" (Gagné). For meaningful learning, task "a" must be closely related to task "b" and so on up the ladder. Thus, there is prior learning (content prerequisites) necessary, and tasks must relate to and facilitate the learning of the next (sequence). Therefore, both cognitive and content prerequisites must be in place to allow the child to progress meaningfully up the ladder from task "a" to "d".

A model to guide mathematical thinking (dialogue or discourse) is shown below. Moving through the model should be fostered through systematic questioning or dialogue.



Explore--Examine relationships through mental images, diagrams, or real objects; classify observations where possible.

Interpret--Make sense of (explain) what was founded through exploration; Translate and express in symbolic form.

Verify--Justify one's conjectures based upon what is already known.

Apply--Solve problems using the new learning gained.

Consider the following examples:

Example A

How much money is 5 dimes?

Let student explore with money or diagrams.

Student counts to get 50¢.

How many pennies are equivalent to one dime?

Student views 10

Guide student in the interpretation.

5 sets of 10¢ each ---> 50¢ or 1/2 dollar

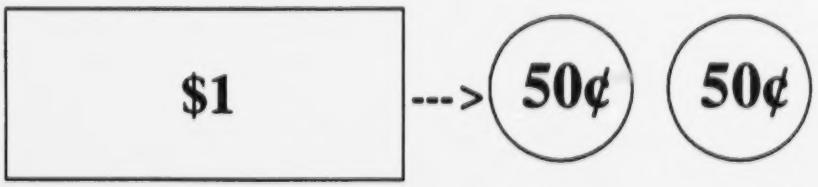
or 5 x 10 = 50 or 5 x 10¢ = 50¢ (1/2 dollar)

Student verifies the above process by relating to a familiar situation.

4 sets of 3 each ---> 12.

or 4 x 3 = 12.

How much money is 1/5 of a half-dollar?



Student makes observations and goes through the same process again. How can 50¢ be changed into 5 equivalent parts?

Student explores.

10¢

Now back to the question, "How much is 1/5 of the half dollar?"

1 of the five dimes ---> 10¢ or 1/10 of a dollar!

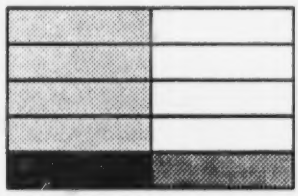
Interpretation: 1/5 of a half-dollar is 10¢ or 1/10 of a dollar.
Therefore, 1/5 of 1/2 dollar gives 1/10 dollar.

$$\frac{1}{5} \times \frac{1}{2} = \frac{1}{10}$$

Apply the new learning with a different model.

Find 1/5 of 1/2.

Let student draw model as shown.



First shade 1/2 of the unit. Then separate the unit in fifths and shade 1/5.

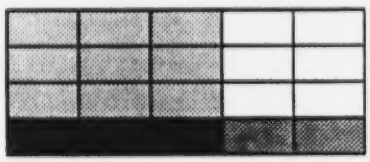
$\frac{1}{5}$ of $\frac{1}{2}$ --> $\frac{1}{10}$ (one part out of ten).

Thus, $\frac{1}{5} \times \frac{1}{2} = \frac{1}{10}$

Extend the new learning to a more complex situation.

Find 1/4 of 3/5.

How do you diagram this situation?

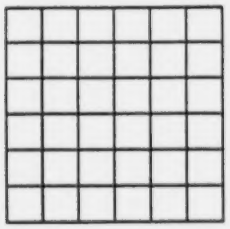


$$\frac{1}{4} \text{ of } \frac{3}{5} \rightarrow \frac{3}{20} \text{ or } \frac{1}{4} \times \frac{3}{5} = \frac{3}{20}$$

How does the numerator of 3/20 relate to the numerators of 1/4 and 3/5?
What is the relationship among the denominators?
Have students conjecture and verify their ideas.
Lead the students to the generalization that, $\frac{a}{b} \times \frac{b}{d} = \frac{a \times c}{b \times d}$

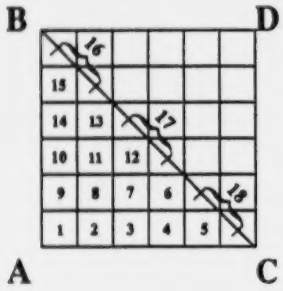
Example B

How many little squares in the big square?



(Discuss notion of area.)
In a 6 x 6 square there
36 square units.

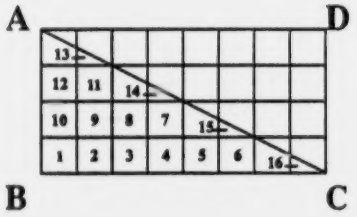
How many square units in half of the square ABCD? (The triangle ABC)



Verify by counting.

Area of the square is 6 x 6. Area of triangle ABC is
1/2 (6 x 6) = 1/2 (36) = 18.

What is the area of the rectangle below?



Area of ABCD = 8 x 4 = 32 sq. units.
What is the area of △ ABC in relationship to the area of the rectangle ABCD?

Area of △ ABC = 1/2 Area of ABCD
= 1/2 (8 x 4)
= 16

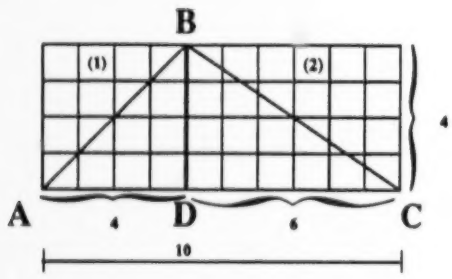
Is this reasoning and calculation correct? Verify by counting.

Discuss the special kind of triangle for which we are finding the area.

Area of a right triangle = 1/2 b h, where

b = base, h = height

Now lead students through questioning to develop the formula for any triangle (generalize).



What is the height of triangles ADB and BDC?

What is the base of triangles ADB and BDC?

What is the relationship between the area of △ ABC and the areas of △ ABD and △ BDC?

Area of △ ABC = Area of △ ABD + Area of △ BDC

= 1/2 (4x4) + 1/2 (4x6)

= 1/2 (4) (4) + 1/2 (4) (6)

= 1/2 (4) (4+6)

= 1/2 (4) (10)

Note this is 1/2 the height (4) times the base (10) of △ ABC. Thus, the area of △ ABC = 1/2 bh.

Verify by finding the area of triangles (1) and (2).

Area of (1) = 1/2 (4x4) = 8

Area of (2) = 1/2 (4x6) = 12

Area of △ ABC = Area of (1) + Area of (2) = 8+12 = 20

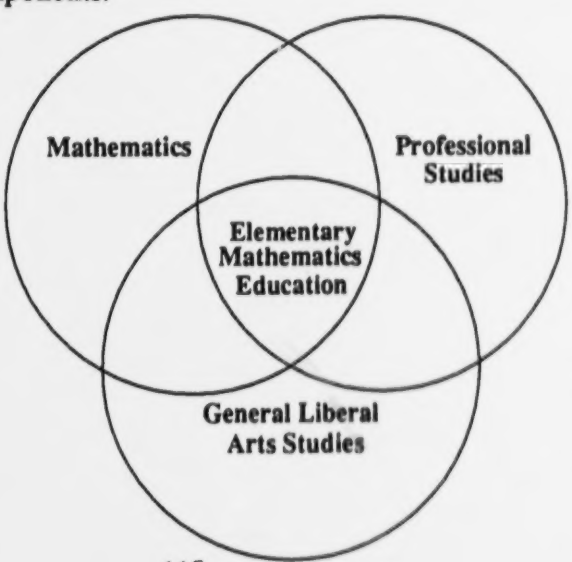
Thus, the formula A = 1/2 bh gives the area of any triangle.

These examples illustrate how to facilitate the development of mathematical thinking (dialogue) through questioning. With time, effort, modeling, and practice, the student will learn to engage in mathematical thinking (explore, interpret, verify and apply) with some bit of proficiency. As the child gains confidence through success, success comes easier.

What Kind of Teacher Education Program Is Needed to Prepare Elementary Teachers to Teach Mathematics?

Ideally, mathematics should be taught by teachers who specialize in the teaching of mathematics. This thesis is based upon the premises that (a) mathematics is a discipline which one must have a good understanding of and appreciation for in order to provide meaningful instruction to children, and (b) mathematics is not a discipline prospective teachers can learn through casual encounter. One or two introductory mathematics courses and a method course, which oftentimes is very general and taught by a generalist instead of a mathematics educator, is not sufficient preparation for prospective teachers. Elementary teachers must be able to teach in a way that maximally facilitates the development of students' mathematical thinking and problem solving abilities and minimizes students' frustration, rote memorization, failure, and anxiety. The skills, knowledge, and confidence to teach mathematics as described herein calls for considerable expertise in mathematics, professional education (curriculum, learning theory, human development, etc.), the teaching and learning of mathematics, and supervised practice in teaching mathematics during internship. However, just increasing the number of credits prospective teachers must complete will not necessarily result in more competent teachers. The problem is what these courses should entail, how they should be taught, and how they are integrated into a program that provides prospective teachers the experiences necessary to become thinkers, problem-solvers and effective teachers of mathematics.

The proposed elementary education program with emphasis on teaching mathematics is built upon the notion that an effective elementary teacher must have a strong liberal arts education. This involves general studies, a concentration in mathematics for elementary teachers, and professional studies (development and learning, curriculum and instruction, measurement and evaluation, etc.). Elementary mathematics education is defined as the intersection of these three components:



In general, prospective elementary teachers should gain *academic knowledge* (the mathematics concentration and other liberal arts areas) in courses completed outside the school or college of education; *methodological knowledge* through courses completed within the school or college of education, including methods of teaching courses and other professional studies courses (curriculum, measurement, learning, etc.); and *clinical knowledge*[10] through supervised internships and seminars. However, these components are not disjoint. There must be considerable overlap, interaction, and integration of all program components since this is the definition of elementary mathematics education. For example, courses taken in mathematics provide the foundation needed for other liberal arts courses and for mathematics methods courses; professional education courses provide knowledge of how students learn and develop, the nature of schools and schooling, and the reciprocal relationship of schools and society; mathematics methods courses utilize, build upon, and integrate knowledge and skills gained in both mathematics courses and professional education courses; general liberal arts courses help prospective teachers understand the relationships among mathematics and other discipline, the arts, society, and technology; and supervised internships provide students with the opportunities to synthesize and apply this knowledge within the problem-solving context of the elementary school classroom.

Consistent with the integrative model described herein, there should be six major program goals. Prospective teachers of elementary school mathematics should be able

1. To demonstrate knowledge in general liberal arts studies.
2. To demonstrate knowledge in appropriate mathematics.
3. To demonstrate knowledge in appropriate professional areas.
4. To demonstrate the ability to engage in mathematical thinking (dialogue).
5. To synthesize and use the necessary knowledge bases to formulate a sound foundation for the teaching of elementary school mathematics.
6. To demonstrate the ability to function effectively within the elementary school setting.

Of course, accomplishing these goals is not an easy or simply undertaking. In the *Guidelines for the Preparation of Teachers of Mathematics*, NCTM (1988) listed 73 specific competencies on the teaching and learning of mathematics that prospective elementary/middle school teachers should demonstrate. There would be little disagreement about the desired outcome of a program designed to prepare elementary teachers to teach mathematics. Namely, prospective teachers should exit the program with the competencies necessary to provide meaningful mathematics instruction to children. What are the means to this end?

Clearly, the preparation of competent elementary school teachers is not solely the responsibility of professional schools of education. The proposed integrative model calls for

[10]The italicized terms are used as defined by National Council for Accreditation of Teacher Education.

university-wide commitment and collaboration. While faculty from the school or college of education must provide the appropriate leadership in the development and administration of the elementary mathematics education program, faculty from several other areas within the university must become an integral part of the program. Thus, we propose the notion of a program faculty involving faculty from various areas within education and liberal arts. The program faculty would collaboratively develop the program goals and objectives, develop and/or revise courses, establish course sequence, and suggest appropriate evaluation of students and the program.

We all know that just increasing the number of courses prospective teachers must complete in liberal arts and/or education will not necessarily result in more competent teachers. The issue of what these courses should entail and how they should be taught must be addressed. There is truth to the old adage "We teach as we were taught." If we want elementary teachers to motivate students to learn mathematics, to engage them in mathematical thought and problem solving, to enhance students' understanding of what mathematics is and help them see the need for studying mathematics, and to help students learn how to learn, then many college-and university-level courses must be taught differently from how they are presently taught. Mathematics courses should emphasize the nature of the discipline, how to do mathematics (the process), and how ideas are developed or derived and how they are verified; that is, prospective teachers and the students they teach must realize that "mathematics is something one does, not something the teacher does to them". Mathematics should not be presented to prospective teachers as an accrued body of knowledge--facts, definitions, theorems, formulas, and relationships to be rotely memorized in order to pass a test.

All courses in the elementary mathematics education program (liberal arts and education) should actively involve students in the learning process. Instructional techniques should demand that students think, question, see relationships, interpret, analyze, draw conclusions, verify, and apply. This is not to lessen the importance of content. We are saying that prospective teachers must have more depth to their content knowledge not just surface level rote memorization. This approach to teaching for understanding calls for university-wide collaborative planning and implementation.

Since several different sequences of courses could lead to the same set of desired outcomes, no specific program for elementary teachers of mathematics is suggested. We do believe, however, that the program should incorporate the following major elements:

1. *Liberal arts* areas which emphasize critical thinking, inquiry, analysis, writing and communication, ways of knowing and the relationships among the disciplines.
2. *Elementary mathematics* including areas such as number systems, informal and formal geometry, algebraic systems, probability and statistics, number theory, sets and logic, and proof making (informal and formal-ways of knowing).

3. *Professional education* areas such as child development, teaching and learning, schools and schooling, instructional media, curriculum development, classroom management, and evaluation.

4. *Mathematics Education* emphasizing teaching for understanding, the nature of mathematics, mathematical thinking (dialogue), problem solving, the language of mathematics, research related to the teaching and learning of mathematics, diagnosis and remediation, current trends and issues in elementary mathematics education, and supervised practice teaching.

The number of courses in each area or the titles of the courses are not very important. What is important?--the objectives of the courses, how the courses are taught, what students are expected to do in the courses, how students are evaluated, the collaboration among program faculty, and the integration of the courses into a program that will provide prospective teachers the opportunity to gain the skills, knowledge and confidence to become effective teachers of elementary school mathematics.

Summary

A cursory review of the literature will support the conclusions that (a) mathematics education (at all levels) in the United States is in trouble, and (b) school mathematics programs must undergo significant changes in order to prepare students to meet the challenges of the future. Many students in elementary, middle school, and high school *rotely memorize* rules and algorithms to pass minimal performance tests but do not *learn* much mathematics. When presented with a choice in secondary school, a large proportion of the students elects not to take mathematics courses beyond the minimum required for graduation. Of the students who complete mathematics courses beyond the basic requirements, many succeed by memorizing rules for manipulating symbols in algebra and for making proofs in geometry and they still learn very little mathematics. As a result, an unacceptable proportion of high school graduates are mathematically "ill-equipped" for college studies or to function in today's technological world (National Research Council, 1989).

A large number of students entering college cannot pursue fields of study such as mathematics, science, engineering, computer science, technology, and preprofessional areas like medicine and dentistry because they lack the prerequisite mathematical skills and knowledge. Unfortunately, many students who have the prerequisite secondary courses fail calculus (their first college-level course)--due largely to how they learned mathematics in high school and how mathematics is taught in college. The facts are that very few students pursue mathematics as a major and even fewer students enter graduate programs in mathematics (the majority of advanced graduate students in mathematics are foreign students). As a result there is a national shortage of mathematics teachers as well as mathematicians in business, industry, and government.

The problems are real. If the United States is to continue as a world leader, remain competitive in technology, trade and economy, and be secure in our national defense, solutions must be sought *now*. Obviously, there is no single, easy quick-fix. However, the authors take the position that highly skilled and motivated teachers, capable of providing meaningful instruction to students, are one of the major keys to improving school mathematics programs. Thus, the first step on the road to developing quality school mathematics programs is to overhaul existing teacher education programs (elementary and secondary).

Elementary school students must engage in mathematical thinking (dialogue). The appreciation of mathematics and the motivation and desire to continue studying mathematics must be developed early. For most students, secondary school is too late--they are already turned off to mathematics. This means the elementary teacher has a vital role to play at a critical time in the child's development and schooling. The kind of teaching and leadership proposed here calls for teachers with considerable expertise in mathematics and the teaching and learning of mathematics. It is unrealistic to expect prospective elementary teachers to gain the expertise needed to teach all elementary school disciplines. The skills, knowledge, and confidence needed to provide meaningful mathematics instruction in elementary school can best be achieved through a teacher education program aimed at preparing elementary mathematics specialists.

The development and implementation of an elementary mathematics education program of excellence would involve significant changes in courses and the delivery of instruction in education and liberal arts. Such a program would prepare highly competent teachers of elementary school mathematics who also have the skills and knowledge necessary to contribute significantly to the overall elementary curriculum.

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WHAT DO MATH TEACHERS NEED TO BE?

Herbert Clemens[11]

Here's a problem:

$$\frac{21}{1320} + \frac{12}{1255} =$$

Give your answer as a fraction in lowest terms.

What is your reaction? My guess is that the reaction of many grade school teachers would be something like "Those numbers are too big, and, anyway, what book did that problem come from?"

Here's another problem:

$$\frac{21^{-2}}{7^{-3}} + \frac{1/7 - 4/21}{1 + 5/7} =$$

Give your answer as a fraction in lowest terms.

What is your reaction? Perhaps this time the first comment of elementary school teachers might be "We're not supposed to know this, are we?"

As a mathematician with absolutely no formal training in education, I can only guess at what a teacher's reaction to these problems would be, but I can tell you for sure what my first reaction is, namely "I can do these problems!" Would I like to do fifty of these kinds of problems? Probably not. (Maybe I wouldn't even like to do five, but one or two would be o.k.) When pressed by the chemistry of a school classroom to reach out to kids, my next reaction might be (and often has been)

> We can probably fool around with this big messy problem and pull together some interesting things about math. In fact, I can probably use this problem to explain some things better than the book can . . . let's see how would I start . . . it doesn't matter if that approach doesn't work for some of the kids . . . after I read their minds a bit, I'll reorganize the problem with them in a way that works for them.

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I like teaching kids and I like the way I teach, otherwise I wouldn't be standing here today. So, to begin my answer to the question posed in the title, the first thing I think a math teacher must be is what I like to think I am (on my good days), and that is *unafraid*. To explain a bit more, let's ask the reverse question, What does it mean to be afraid? It means anxiety when confronted with that which is unknown or unfamiliar, it means jumping to the assumption "I cannot deal with this new person or thing, and so this encounter is going to be a negative, defeating personal experience." If that's what we mean by being afraid, then many school teachers I know are afraid of math.

What else should a teacher be? Again, let's pose a question: Are the above problems are "fun"? Quite frankly, no. Can learning to solve them be fun? Maybe in one specially configured circumstance, yes, but not "over the long haul." The numbers are big, the multiplications and additions needed get very boring very quickly (unless we use a calculator), and, all in all, there are a lot more fun ways to spend an afternoon. I'm much too pseudo-sophisticated and cynical to be won over by the "math-is-fun" crowd. Interesting? Quite often, yes. But fun? No. Doing math is a lot like developing a spiritual component to life--when you are young and immature you do it because your parents force you to, when you grow up you understand its importance in your own life and you do it in your own personal way. The enterprise of mathematics is too basic and important, with too much beauty, history and depth, to be trivialized into "fun and games."

So the second thing a math teacher must be is what any good cleric must be, namely *reverent*. If we are good math teachers, then by our demeanor and way of talking about it, we reflect respect and reverence--not some ostentatious false piety, but a belief that enterprise is worth it. True respect and reverence for mathematics, as for religion, rests on the belief that its content is solid enough to be doubted, questioned, probed, and attacked. The outcome is usually that the basic truths are unmoved, but that the individual who has the integrity and intelligence to question, probe, and attack has learned and grown in the process. We cannot expect young, immature minds to be capable of appreciating much of the beauty and depth, but we really must configure experiences--even when we have to force them a bit--which open for our children the opportunity to appreciate these things in adult life. The question "We're not supposed to know this, are we?" is the mathematical equivalent to some of the questions that were current during my adolescent religious training, like "What kind of a sin is it to French kiss for one minute and thirty seconds?"

What comes next in this scout's oath of math-teacher virtues? I'd say it's the realization that, in the area of mathematical culture, the United States is an underdeveloped nation. All measures of the ability of our school children and general populace to deal with mathematics rank us far down on the roster of nations. Our power in advanced research and technology is derived increasingly from scholars who receive their basic education in other mathematically developed countries. So our math teachers, and all the rest of us,

should be *humble*. We're a poor mathematical nation, we're ignorant, and the most important first step in attacking ignorance is to admit to ourselves that we are ignorant. In the fight for mathematical literacy, we're the underdogs. This may give us energy and determination, which is all to the good, but it should also induce a certain quiet sense of shame, and of admiration of those who do better than we do.

What's next? Let's go back to the reaction "I can do this problem":

$$\frac{21^{-2}}{7^{-3}} + \frac{1/7 - 4/21}{1 + 5/7} =$$

In fact, this problem is a terrific opportunity! It is complicated, like most interesting things, and it demands that we analyze it, break it up into simpler "steps." For example, I can work with

$$\frac{1/7 - 4/21}{1 + 5/7}$$

where I know that I don't change the big ratio if I multiply it by

$$1 = 21/21.$$

This problem is an opportunity to talk about clever ways to write the number 1. Many, many complicated fractions problems get a lot simpler if one writes "one" in a helpful way, but learning how to do that comes from "getting the hang of it," not from learning a bunch of rules. So a math teacher must be *opportunistic*, and must pick the right moment to do the right thing.

In order to exploit opportunities, a math teacher must be *versatile*. Children are so different, one from another, in the ways they think, visualize, and learn. A teacher doesn't need one technique to teach fractions or place value; he or she needs three or four. He or she needs a file cabinet full of different materials, needs to be able to keep two or three different approaches going at the same time in the same lesson, and needs to have alternative approaches available if the current one isn't working. In my experience, no particular technique for presenting a given lesson on a given day is reaching more than 4 or 5 students out of a group of 24. (Fortunately it's not always the same group of 4 or 5!)

All these virtues are part of feeling in control of one's math. All good math teachers are *in control* of their math--ultimately this is reflected in the ability to change the rules if they need to and to be able to satisfy themselves and others as to whether the change is legitimate. To give a couple of very concrete examples of what I mean by being "in control," we might write

there is a number whose square is -2,

or we might write

$$10101 = 21.$$

Both of these are perfectly good mathematical statements if we explain them appropriately.[12] So we drive the mathematics, not the reverse. We're better than the book, or at least we can be, if we put our minds to it!

So far I've said nothing about what mathematics a math teacher should know, and that's not because I think that the question is unimportant, but I believe I have mentioned those qualities, or lack thereof, which distinguish teachers, and the population in general, in mathematically developed countries from our own. Empirical evidence indicates that these factors may be relevant to math education.

But what about subject matter? It is very appealing to think that there is a set of quantitative skills which we can give to math teachers which, together with some good teaching technique, will do the job. There are some problems with that. For example, the little I know about the research in math education says that better results come from teachers who inspire and who command respect for their quantitative ability rather than from teachers who know some particular type of mathematics, however enlightened and well designed.

This is not to say that the teacher's command of the subject is unimportant--it is essential. I can't imagine a teacher who is not bright and well trained in math feeling in control, opportunistic, and unafraid! But the criterion for subject matter should be its mathematical integrity and its relevance to quantitative experiences and questions which are natural to human beings. This leaves a lot of latitude in choosing subject matter. Basic quantitative insights and techniques, well exercised in any of a number of settings, are readily transferable by students, whereas the most enlightened and carefully drawn set of mathematical facts, in the hands of those with little insight, is a dangerous weapon! So math teachers have to have a feeling for math--there's just no substitute for that, which may say more about whom we should go after to become math teachers than it does about what particular mathematics they should learn.

Examples of Elementary School Mathematics

That said, I'll tell you what math I would talk about if I were teaching in elementary school. But I want to insist that another choice made by someone else can be equally valid,

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[12]Mathematicians understand the square root of -1 to be written as i. So the square root of -2 is $i\sqrt{2}$ (because $(i\sqrt{2})^2 = i^2(2)$, or $2(-1)$, or -2. The second statement has to do with expressing the same quantity in different number systems. In this case, twenty-one is represented in base two as 10101, where the places are worth, from right to left respectively: 2^0, 2^1, 2^2, 2^3, 2^4. Thus 10101 equals $(1 \times 2^4) + (0 \times 2^3) + (1 \times 2^2) + (0 \times 2^1) + (1 \times 2^0)$, or $16 + 0 + 4 + 0 + 1$. In base ten, the places are worth, from right to left respectively, 10^0, 10^1, 10^2, 10^3, and so on, so twenty-one is represented as 21 because it's $(2 \times 10^1) + (1 \times 10^0)$, or $20 + 1$.

with equal mathematical integrity and equal relevance to quantitative experiences and questions that are natural to human beings. Let me list four areas of knowledge which I would like kids to get before they leave grade school:

1. place value, the base-10 number system
2. operations with fractions
3. estimating, approximation, margin of error
4. lengths, areas, and volumes.

I'd like to make some comments on each of these areas and to give some examples "at the high end" of what I would like to get teachers and kids to know about them.

Place-value:

$$10101 = \mathbf{21}.$$

If that equation makes sense to you, you know more about place value than I want kids to know and about as much as I'd like most teachers to know. The left side of the above equation is, let's say, Mayan, and the right side is the equivalent phrase in English. The intellectual (mathematical) content of the two phrases is the same--it's just that, by historical accident, people counted with their arms in the land where the Mayan language developed but they counted with their fingers in the land where English developed:

The left-hand column is in Mayan, the right-hand column is the exact translation of the same mathematics into English.

How to add:
When you get two in a column replace it with a one in the next column to the left.

Multiplication table:

	0	1
0	0	0
1	0	1

How to add:
When you get ten in a column replace it with a one in the next column to the left.

Multiplication table:

(Remember 3rd and 4th grade)

	Sample problems	Sample problems
The left-hand column is in Mayan, the right-hand column is the exact translation of the same mathematics into English.	10101 x 11 10101 10101 111111	21 x 3 63
	1010.1 10 ⌊10101.0 10 010 10 010 10	10.5 2 ⌊21.0 2 010 10

Any differences between the two columns above has about as much to do with mathematics as the differences between good translations of *Brothers Karamazov* into, say, Spanish and French. I'd like teachers to understand that our decimal system is one of several languages with which we can express mathematical ideas just like English is one of several languages with which we can express poetic ideas. Mathematical notation *does* affect mathematical thought, facilitating some concepts and obscuring others--if you doubt that, just try to do a large multiplication problem using Roman numerals. But there is a fundamental difference between the concepts themselves and the system we use to express them.

Operations With Fractions:

$6 + 2 = ?$

means

How many 2's are there in 6?

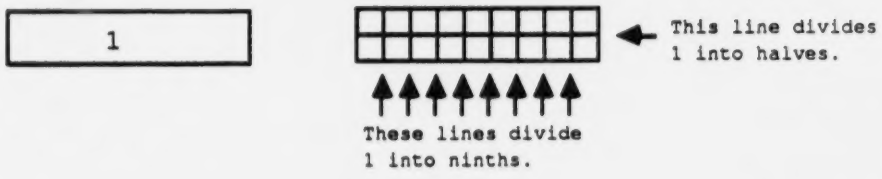
So too:

$1/2 + 2/9 = ?$

means

How many 2/9's are there in 1/2?

This latter is a problem about halves and ninths. Let's make a suitable model of the number 1 in which we can easily see halves and ninths of it:



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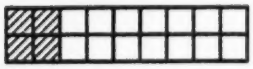
Here's 1/2 (of our 1):

1/2

Here's 2/9 (of that same 1):



2/9

So how many of

fit into

?

We'll have to do some cutting and rearranging, but the answer should be:

Two and one-fourth of these things:

fit into this thing:

I would like a fifth-grade math teacher to be able to make the entire journey, without skipping any of the necessary transitions, from the above lesson to the rule "invert and multiply."[13] Perhaps calling for the depth of knowledge and understanding necessary to make such a journey implicitly advocates the introduction of "math specialists" to teach fifth- and sixth-grade math. At least there should be some teacher in any given school who can make the journey.

Why do I think that the second on my list, understanding operations with fractions is so important? I guess it's because of my experience teaching mathematics at the college level. Calculus becomes a memorization game instead of a learning experience because

[13]The illustration above produces a graphical approach to solving 1/2 ÷ 2/9. Using "invert and multiply" yields the same answer, but without a concrete referent: 1/2 ÷ 2/9 = 1/2 x 9/2 = 9/4, or 2 1/4.

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students don't understand algebra. Algebra becomes a memorization game instead of a learning experience because students don't understand fractions. For example:

$$1/x + 1/y = (y+x)/xy$$

Is this equality correct? If so, why? If not, why not? This is just adding fractions by finding a common denominator, or, if you want, we just multiply

$$1/x + 1/y$$

by 1 in a fancy way:

$$1 = xy/xy$$

so that

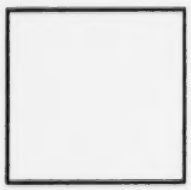
$$\begin{aligned} 1/x + 1/y &= 1 \cdot (1/x + 1/y) \\ &= (xy/xy) \cdot (1/x + 1/y) \\ &= (xy/xy) \cdot (1/x) + (xy/xy) \cdot (1/y) \\ &= (y/xy) + (x/xy) \\ &= (y+x)/xy. \end{aligned}$$

Squint a little bit, see 3 instead of x and 5 instead of y, and you have a problem in adding fractions. If you knew how to add fractions with unlike denominators, you know how to do this algebra problem. There is no other area of elementary school mathematics more intimately related with what comes later.

Estimating

Lest this turn into a math lesson that doesn't know when to stop, I'll combine items 3 and 4 on my list and combine my example of the type of estimation I find useful with the type of geometry I find useful:

If it takes one can of paint to paint the inside of this square



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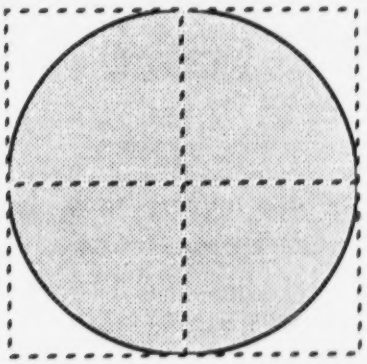
estimate how many cans of paint it takes to paint the inside of this circle:

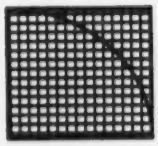


In other words, estimate the value of the number π. Kids should be accustomed enough to estimating size to decide that it will take less than four cans of paint the inside of the circle, and to give convincing reasons why it will take more than two cans. But suppose I wanted to know the answer to within one decimal place. What does that mean? What sort of strategy might I use to get the answer within the desired margin of error? These are fundamental questions about human quantitative experience. The questions are deep, interesting, yet accessible. Learning to deal with them successfully is easily transferable to other quantitative situations. Maybe they also give us a chance to meaningfully touch some of the concepts of higher math in a way accessible to kids.

Some useful strategies for the particular problem we introduced above:

1. It is sufficient to solve "one-fourth" of the problem:

2. A fine grid will help:



3. If it takes one can of paint to paint the big square, how much paint does it take to paint one of the tiny squares? (There are 19 in each direction.)

4. How many tiny squares lie entirely inside the quarter-circle?

5. Use this information to give a lower estimate for the amount of paint needed to paint the quarter-circle.

6. How many tiny squares completely cover up the quarter-circle?

7. Use this information to give an upper estimate for the amount of paint needed to paint the quarter-circle.

8. How far is your lower estimate from your upper one? So how close are you to the exact value of one-fourth π?

9. Now multiply your estimates by four. What happens to your margin of error?

I've tried to pick just a few examples of the kind of mathematical skills I think a math teacher might aim for. Even in these examples, there are many ways to deal with them successfully. There are many ways to teach about them, and many ways to think about them, which have mathematical value and integrity, and which prepare kids for quantitative success. Any way which gets kids to think is good--there are no end of good ways. Good teachers, when they aren't too tired or overburdened, will find the way that is most natural to them.

Do my choices of examples mean that I don't think rote arithmetical skills are important? No, I don't think that at all. It should go almost without saying that kids have to be able to do the traditional computations such as adding, subtracting, multiplying, and dividing whole and decimal numbers with several digits, and do these computations rapidly

and accurately. That's the base; those are the calisthenics; you have to do the calisthenics and keep doing them to stay in shape, or you can't play the game. But you also have to play the game, not just do calisthenics!

Computers Relatively Marginal

So far, I haven't said anything about subject matter and technological innovation, for example, computers. Maybe what math teachers need is more knowledge of computers and their use in mathematics education. Why didn't I put that on my list? Maybe what we need in our math classrooms is more use of computers and hand-calculators. Going back to my remarks at the beginning of this talk, let's use an empirical test. I don't think that you can make the case that the mathematically developed nations, such as France, Japan, or the Soviet Union, are the ones with lots of technology-related math education. Let's not worry too much about the rationale for teaching with computers and calculators. Let's just look at the empirical evidence worldwide. I think that the effect of the computer revolution on math should be seen as parallel to the effect of the television revolution on reading. Both revolutions have unalterably changed how we receive information, how we learn, and how we think; but I feel that computers affect our efforts to learn and do mathematics in much the same (relatively marginal) way that television affects our efforts to learn to read and do reading. In fact, perhaps computers will eventually have the same kind of negative effect on doing mathematics that television has on doing reading.

Fundamental Questions

I've tried to give a feel, by example, for the kind of mathematical acumen an elementary school math teacher should have, and the kind of mathematical goals he or she might well have for the kids. It doesn't make sense for me to try to outline an entire curriculum--the National Council of Teachers of Mathematics (1989) has recently done that far better than any of us could. And besides, as I tried to stress at the outset, it's not always the particular topic or approach that matters most. For me the more fundamental questions are as follows:

Does the subject matter have some mathematical integrity?

Does it have beauty and order?

Does it respond to a quantitative issue which is natural and basic for us humans?

Can this teacher teach it with conviction, and with some feeling for its essence?

Profession in Danger

Finally, why in the world does a research mathematician, with a safe and comfortable job at a nice university, worry about grade school math? I suppose there are some selfless, noble motives that one could cite, but for many of us the issue is more crass and mundane than that. Our profession is currently in danger, and the danger is directly traceable to the fact that our culture no longer values what we do. Our schools reflect our culture and they transmit its message, too--go to school and get training so you can get a job and make money, preferably a lot of money. Worry about training, but don't worry about education, that's too impractical for all but the ivory tower types. Get grades, not ideas.

So we have to import our scientists from other countries, and even that is becoming more difficult as opportunities for those people increase for a career in their home countries. Our university students complain that their math teachers don't speak English. Of course not, when the students' own older brothers and sisters, and fathers and mothers, can't compete for university teaching positions because of inferior scientific qualifications!

All aspects of mathematics, from grade school to advanced research develop together, or in the end, none develop. Some of us find mathematics exquisitely beautiful, the quantitative equivalent of the best poetry and literature. And if history is any guide, future generations will often find mathematical theory, developed now for aesthetic reasons, astoundingly useful. But the entire enterprise is threatened from within because it is not valued by our young, and we mathematicians share the blame for that. We are often intellectual "yuppies," concentrating only on that which is at the pinnacle, because that's where the personal rewards are, but forgetting to attend to the base. Together, let us attend to the base lest the entire structure crumble!

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PARADES OF FACTS, STORIES OF THE PAST: WHAT DO NOVICE HISTORY TEACHERS NEED TO KNOW?

Suzanne M. Wilson[14]

There appears to be reason for concern. American students believe that Arizona is the capital of Pennsylvania. They think that the Great Depression took place *before* World War I and that the New Deal was a land purchase that had something to do with the purchase of Alaska. They certainly don't know the names of all of our presidents; as a matter of fact, some of them don't know there was a president named Harding. This frightening lack of knowledge about the past has been thoroughly documented, most notably in the results of the National Assessment of History and Literature reported by Ravitch and Finn (1987).

Although not as well known, similarly depressing reports have been made of social studies teaching. Teachers talk; students record dates, names, events. Occasionally, the march through endless lectures is broken with a filmstrip. Seldom are students engaged in critical thought; for many of them, history class remains the place where they memorize dates, storing yet more worthless information in the corners of their minds reserved for school knowledge. They have no sense for the potential that such knowledge holds for them, what meaning it has or how they might use it. Consequently, Americans have little sense of themselves as historical beings, individuals whose lives are determined, to some extent, by where they came from.

Consensus seems to be then, whether one is talking about what students learn in history class or about how students are taught, that social studies teaching and learning are in desperate straits. Although teachers are but part of the current problem, in this paper I focus on the knowledge, skills, and dispositions that beginning history teachers in secondary schools need if they are to affect change in current practice. For the purposes of my argument, I draw many examples from the teaching of United States history since it is a mainstay in the elementary and secondary school curriculum. However, I believe the points I make about U.S. history teachers and teaching are more generally applicable to many courses housed under the title of social studies.

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What Should Students Learn in History Class?

Implicit in any evaluation we make of the quality of teaching and learning is a set of assumptions about *what* students should learn in school. That is, our disdain for what students are not presently learning in high school history classes is, in large part, determined by what we think they *should* be learning. Yet there is little consensus, even among experts, about what secondary history education is about. The field has a history of its own, one that is largely characterized by disagreements about the content of the social studies curriculum. Shouldn't history teachers, some individuals ask, teach students citizenship values? "No!" others argue, "history teachers should teach the subject matter--American, African, ancient, European, third world *history*." The arguments continue, opinions and positions abound, and history teaching is alternatively characterized as values clarification, critical thinking, issue-oriented and thematic, or discipline-grounded.

But the camps that various social studies educators have defined for themselves are unproductive illusions, false dichotomies in a sense. There is no need for "either-or"s in social studies--one doesn't have to teach about American history *or* about citizenship, one needn't teach about critical thinking *or* the history of third world nations. Social studies teachers, like any other teachers, have multiple agendas and responsibilities. Yes, they are supposed to teach their students to be good citizens; yes, they are supposed to help students clarify their values; yes, they are supposed to hand down to students the history of our past, as well as the histories of other peoples.

Those goals are not antithetical. Rather, they may all be different ways of talking about the same set of concerns--that our schools are in the business of producing an educated citizenry, a citizenry which knows enough about the past to have a sense of itself as a body politic that has evolved out of a set of social, cultural, political, and economic traditions. Moreover, an educated citizen knows how to think analytically and critically. Social studies teaching does not have to focus on values clarification *or* critical thinking *or* subject matter. Rather, all masters can be served if we represent the disciplines being taught with integrity. As they teach students about the American Revolution, history teachers can teach students to think critically. Not by using some prepackaged curriculum designed to foster higher order thinking, but by presenting them with the alternative explanations and interpretations that historians have generated about that period. Thus, students can learn both about the content--the Boston Tea Party and the Intolerable Acts, Sam Adams and the Committees of Correspondence, Lexington and Concord--and about analysis in historical thinking--examining different interpretations of the same set of characters and events, weighing the evidence presented by historians and source materials, discussing the strengths and weaknesses of various accounts.

Similarly, teachers can help students examine their own values by helping them examine how the values of various sectors of the American public have changed over time.

For example, legislation passed during the New Deal altered the nature of the relationship between the people and the federal government. Social insurance, the idea that the government had a responsibility to help citizens who were destitute or disabled, gradually became part of the American mind-set. Students in today's classrooms have not had the opportunity to think about the assumptions they make about the role that the federal government should or does play in their lives. Yet a teacher who is teaching students about the New Deal could choose to use that unit as an opportunity to have students examine their values and assumptions, prodding students to develop logical arguments and rationales for the values and beliefs that they hold. A plethora of similar opportunities exists: Students can examine their beliefs about basic human rights as they learn about slavery; teachers and students can explore the issue of genocide as they learn about the Holocaust; lessons about Watergate and Contragate can surface fundamental assumptions that students make about the balance of powers in our government.

Good history teachers can and do teach students both the subject matter of the course and how to think critically about themselves, their values, the world around them, and their place in that world. And educating students about their past in this way, empowering them to think critically about the present by asking questions and being skilled in answering them, is a form of citizenship education. Such students have the knowledge and skill to examine the status quo, actively participate in changing what needs to be changed, and defending what needs to be protected and nurtured.

So What Is Good History Teaching?

The image of good teaching upon which this paper is based, then, is one that is grounded in subject matter. It is a disciplinary-based conception of history teaching that presupposes that one major goal for teaching history is the communication of historical knowledge--the central facts, concepts and ideas of the discipline--and the nature of the methods employed by historians--for example, the role played by interpretation and narrative. This conception also presupposes that knowledgeable teachers can use their knowledge of history to further other goals--developing critical thinking skills, teaching students to communicate effectively, helping students identify and clarify their values, thus contributing to the schooling of an educated citizenry.

But by claiming that students should learn about the more interpretative aspects of history, I am not suggesting that we revisit the "new history" curricula of the 1960s. Developing an awareness in students of the nature of historical knowledge is not equivalent to attempts to make students into "little historians." History teachers may have students "do" history in order to develop a sense for the interpretative nature of historical knowledge, even though they are not committed to producing miniature Beards or Bailyns. Teachers may, however, engage students in activities that *resemble* history, that expose them to the nature

of inquiry in history, and develop in them patterns of reasoning that are appropriate in asking and answering questions of a social nature. Teachers think about the methods of analysis and critical thought that have been developed in history, as well as help their students in other social sciences, and translate those methods into knowledge and skill that they can develop.

In order to teach history in ways that accurately represent the discipline and develop in students the dispositions to be active learners, considerations of alternative pedagogical strategies are paramount. If one wants students to develop an understanding of the *doing* of history, children must be engaged in a variety of activities. Simply telling them that historians use specific methods in interpreting data will not suffice. If students are constantly told information, an implicit message may be sent that there is something absolute or final about the material being presented. It is not sufficient for history teachers to be good storytellers, for the stories of the past are neither settled nor in agreement. If historical knowledge is interpretive and underdetermined, however, and teachers want to communicate that to students, they must consider instructional strategies that will facilitate the development of that kind of understanding. Sometimes teachers may tell stories, but at other times they may want students to write their own accounts or read various, conflicting accounts depending on what their want students to learn. Teachers must reflect on the content they want to teach and on the knowledge and experiences of the students they are working with, eventually selecting an instructional method and creating an educational environment that can satisfy their dual concerns of content and audience.

Good history teaching, then, requires teachers who are knowledgeable about the subject matter, who are skilled at creating educational settings in which students may acquire similar understandings, and who constantly reflect on the interaction of concerns for content, students, and goals. In the following section of this chapter, I describe a series of lessons planned by Sean, a first-year teacher. Because good teaching requires intentional action, I will describe both the teacher's instructional strategies and his rationale for his choices. Following this brief description of Sean, I explore the kinds of knowledge and understanding Sean possesses about history and about teaching that allow him to think and to act in the way that he does.

Sean: Learning to Teach the Great Depression

Sean knew a little about the Depression and New Deal from a few classes he had taken in history and political science as an undergraduate. He knew, for example, that F.D.R. was a controversial figure, that the stock market crash did not cause the Depression but was symptomatic of larger economic problems, and that the New Deal consisted, in part, of a series of legislative acts that were designed to stimulate the economy and reform some of its ills, all the while providing relief to some sectors of the American public.

Sean was pretty sure that his students would have little knowledge of either the Crash or the New Deal. In his unit, he wanted to cover the political and economic climate of the time, as well as the social and cultural aspects of the period. Thus, he wanted students to learn about F.D.R.'s personal and political history; he wanted students to understand the destitute conditions many people endured during the Depression and Dust Bowl; he wanted students to learn about some of the personalities of the time--Eleanor Roosevelt, Frances Perkins, Harold Ickes, Father Coughlin, Huey Long, John Lewis, among them; and he wanted students to understand the controversy associated with F.D.R.'s administrations.

Sean planned his instruction by first examining the textbook. Noting that the textbook authors had primarily focused on political issues and debates during the New Deal, and that they appeared to be F.D.R. loyalists, Sean went back to several texts he had read as an undergraduate about this period for additional information he could use to augment the rather one-sided and underdeveloped textbook account. In addition to using historical and political science texts, he went to the library stacks and found Terkel's *Hard Times*, Steinbeck's *Grapes of Wrath*, and a collection of Margaret Bourke-White's photography.

The unit Sean eventually taught consisted of a number of activities. During the first four days of the unit, he delivered a set of mini-lectures on various aspects of the Crash, F.D.R., and his New Deal legislation. The information he presented during these lectures was an amalgam of stories and facts that Sean had culled from his personal library and from the textbook. The lectures were supplemented with teacher-led discussions of issues such as laissez-faire capitalism, social insurance, labor and unionization, and the Dust Bowl. During these classes, Sean was the center of attention, monitoring how and when the conversations progressed, asking students questions about the topics covered in the textbook reading, tying in current events when appropriate. During several other classes which focused on the social and cultural history of the period, Sean constructed small-group activities for his students in which they alternatively examined slides and photographs of Dust Bowl farmers, soup lines, and Hoovervilles; read excerpts from *The Grapes of Wrath* and *Hard Times*; and listened to music of the period. Asked why he included these lessons, Sean explained:

> When kids are taught that history is only what happened in the presidential elections and in Washington, D.C., they think, "Oh well, no wonder history means nothing to me. There's stuff that's happening there [in Washington] and I don't know about it either. No big deal." I think they need to see how common Americans are affected and affect decisions that have been made. I want them to understand what *life was like*. I want them to understand that history is more than elections. It's a way of thinking, of acting. It's about ways of life.
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> I want [my students] to learn that history is not just presidents and prime ministers. That it is ordinary people. I want them to connect in some way to

> the material and not just read it and digest it and spit it back. I want them to *become* the material, if only for a moment. I think that kids think that all history is is a bunch of stuff that already happened that was sort of inevitable. That history is just sort of stuff that happened. They say, "This already happened. There is *nothing* we can do about it." And I say, "Well there is something you can do about it! I also tend to think that they look at the present-day world as history. It's stuff that is going on and there is nothing they can do about it. They need to understand that *that* is not history. I want to get them out of this passive role.

In addition to his lectures and small group activities, Sean included a lesson called "You Are the President." He explained:

> I use a worksheet to organize the material. I say, "Here are a bunch of areas that Roosevelt wanted to change things in. He wanted to get people working, get people eating, get business back on its feet, and banking, and the farmers. How did Roosevelt go about solving these problems?" What I do first, though, in order to engage their minds, is give them the worksheet and put them in groups and say, "Okay, here is problem *x*. One quarter of the American populace is not working. What would you do as president of the United States? How would you get people back to work?

Asked why such an activity was important, Sean said:

> I put them in F.D.R.'s shoes because then when I talk about what actually happened, it's not just history, it's not just something that happened 50 years ago. Instead, it's "Well, how did I do?!?! How would *I* have done if I was president of the United States then?" I think that that would engage them a little bit more.
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> I have this conception that the reason why kids hate U.S. history is because teachers make them learn stuff like facts. They give them a test and they give them ten sets of letters and say, "Explain what the letters stand for and the importance of each." I think the kids just go "Blah! None of this is important!" And they are right because the facts aren't important! I would rather have them learn things about the little guy, about minorities, about the other stories that the books do not tell. . . . This activity puts students in the shoes of people of the time. Now historians will tell you that that's a problem because we think differently now and kids don't necessarily understand that but I say, "What's more important here?" I think my job is to get them excited about history so they'll go on to learn more.

Sean concluded his unit on the Depression and New Deal with two activities: a debate and a whole-class discussion of the success of the New Deal. The debate Sean organized his class around concerned the question, "Was the New Deal *new*?" He assigned all of the students to sides, and presented them with some materials he had found to help them

prepare to support one or the other position. After two days of debate and conversation, Sean led a large group discussion with his students concerning the range of interpretations about the success of the New Deal.

In this class, he presented students with three alternative perspectives on the question, "Did the New Deal work?" in which one historian claimed that F.D.R. had saved the country, another historian suggested that World War II pulled the country out of depression, not the New Deal; and a third historian suggested that F.D.R. failed to save the country because he did not take advantage of the fact that he could have made some significant and radical changes in our political, economic, and social structure had he been so inclined. The class then discussed these three perspectives, and Sean ended the period by suggesting that students should draw their own conclusions based on the three arguments.

It is clear that Sean, even though he is only a novice at teaching, is thinking about subject matter, students, learning, and teaching as he considers what and how he should teach. But what does Sean have to know in order to make pedagogical decisions wisely? What knowledge, skill, and dispositions are necessary for him to make the appropriate instructional choices?

What Do Beginning Teachers Need to Know?

The list of understandings and abilities that teachers should possess is endless. Rather than delineate a complete list, I will discuss two aspects of the knowledge of beginning teachers: subject matter knowledge and subject-specific pedagogical knowledge. Within each of those dimensions, I propose that we focus on two features of beginning teachers' knowledge.

Subject Matter Knowledge

Proposition 1: Social studies teachers should know one subject matter within the social studies deeply. Good teachers are dedicated to exposing their students to the richness and wonder of the subject matter they teach. Good history teachers, for example, want their students to understand that history is interesting and exciting, full of fascinating stories and colorful people. They also want their students to understand themselves as persons placed in a context that has been developed and shaped by what has gone before. Teachers who themselves do not understand history in this rich sense cannot help students develop such understandings.

But what does it mean to have deep or rich knowledge of something? Deep knowledge of the "stuff" of American history is not easily measured. It is not simply a matter of *more* knowledge, that is, the ability to recite more dates, recognize more names, recall more events. Rather, it is an elaborated understanding of historical phenomenon.

There are at least four qualitative dimensions along which we can consider depth of historical knowledge.

First, depth of knowledge can be described as *differentiated*, that is, teachers can understand the main components and subcomponents of a concept or event. For example, an American history teacher can know that there were three major aspects of the Social Security Act as it was proposed in the New Deal: aid to senior citizens, unemployment insurance, and aid to dependent children. Differentiated knowledge of the subject matter, then, means that a teacher perceives and understands the components, dimensions, or features of a particular idea in a social science. In other words, the teacher has skeletal knowledge of the concept or idea.

Differentiated knowledge of the subject matter is essential for teaching. Teachers need to be able to accurately represent the subject matter of instruction to students. A teacher whose knowledge of social security is limited to the fact that each month a portion of his salary is withheld for social security may fail to communicate to his students that social insurance as embodied by the Social Security Act is a much larger issue than the social security checks that retired persons receive. Clearly, without differentiated knowledge, teachers would not be able to distinguish what was important to teach about the subject matter, separating the wheat from the chaff so to speak.

A second aspect of deep historical understanding is how *qualified* the knowledge is. Qualification reflects an awareness of the fact that historical knowledge is contextualized and underdetermined. These two factors lead historians to frequently *qualify* their explanations of the past, by explicitly stating that the conclusions they draw are bound both by the contexts within which events took place and by the undetermined nature of their work.

One of the ways that the subject matters that finds their way into classrooms is simplified is by the neglect of contextual information. In many textbooks, for example, the New Deal is portrayed as an innovative, bold, and radical program of legislation proposed by F.D.R. with the help of his Brain Trusters. But many measures that F.D.R. took were based on programs that had long before been implemented in European countries. It is unlikely that this information could be found anywhere in the textbook. Similarly, many textbooks fail to explicitly state that the content of the text is knowledge as it can best be determined presently. Material in textbooks is *not* presented as interpretation but as hard, cold fact. Students, for example, read about *the* causes of the French Revolution, and are seldom told that there is disagreement among scholars about what the actual causes were, how they were related to one another, how they interacted. Students who never learn to treat texts as sources of information rather than authorities are seriously limited in their ability to actively and constructively think critically about the information that they are presented with (Wilson, 1988).

Historians entertain many hypotheses and search for the complete set of causes that contributed to a phenomenon, and the process of developing an interpretation involves selecting, sorting, and sequencing those causes, as well as establishing priorities among them. But the prioritizing of one cause over another does not lead historians to the conclusion that their candidate for primacy is the *sole* cause. Most remain humble enough to acknowledge the existence of other, albeit in their opinion less central, causes. Teachers must have qualified knowledge of the subject matters they teach if they are to expose their students to the nature of understanding and knowledge.

A third characteristic of deep knowledge of the subject matter is how *elaborated*, or detailed, a teacher's understanding is. This dimension recognizes that teachers can possess knowledge of an event, person, concept, or idea that goes beyond the skeletal pieces associated with differentiated knowledge of subject matter. Details play an important role in the social sciences, often providing new insights into old questions and allowing social scientists to generate more refined or, sometimes, novel, explanations for phenomena. In other words, knowledge of detail often correlates with knowledge of the complexity of the problems that historians wrestle with, an understanding of the subtle distinctions that make the obvious not so obvious. An extended example from an American history class will illustrate this point (Davidson and Lytle, 1986).

Most students of colonial history know that the Jamestown colony had a high death rate throughout its early years; for example, despite the fact that over 3750 settlers migrated between 1619 and 1621, the population of the colony hovered around 700. An astute student would be able to generate a number of valid reasons for this phenomenon: inadequate housing, disease, contaminated wells, poor diet.

The factors I have listed are all reasonable; in fact, all of them contributed to the startling death rate which was somewhere between 75 and 80 percent. But if one knows two details, the picture changes. First, the death rate during the plague epidemics in Britain in the 14th century never exceeded 50 percent. It is puzzling that Jamestown would have a death rate higher than that of the worst years of the plague. Second, there was a law that required Virginians to plant corn. Another anomaly: In a colony where people are starving and corn can be grown easily and efficiently, why would the government mandate the planting of corn?

Knowledge of these details (and others) and the paradoxes that they create when placed against the dire conditions in Jamestown led historians to discover that Virginians were funneling all their physical and financial resources into the cultivation of tobacco. To shorten, and assuredly oversimplify, the example, what one can conclude is that the reasons for the extraordinarily high death rate of the Jamestown colonists were not all dependent on the fact that the colonists were "fighting the elements." Rather, the colonists were

themselves contributing to the inflated death rate by the conscious decisions they made about how to invest their time, energy, and resources.

Even this oversimplified example serves to demonstrate how complicated and complex historical phenomena are. There are levels of understanding any historical problem and knowledge of details is essential for acquiring knowledge of those multiple levels. In the case of Jamestown, knowledge of the high death rate and the horrendous conditions leads to one kind of understanding; knowledge of a few details like the law for planting corn sharpens and changes (to some extent) that understanding.

Granted, not all details are equally relevant. But weighing the relative value of details is a slippery issue--the salience and significance of details are dependent on a plethora of variables, including the questions being asked and the context in which the phenomenon took place. It may very well be true that I don't need to know whether Huey Long had a pet; yet, it is essential that I know that Nixon had a dog if I am to entirely understand his "Checkers" speech. Additionally, it is often the case that teachers use such details to motivate students. Students care more about Gentleman Johnny Burgoyne when they hear about the wagonloads of French champagne. In the midst of misery, here is a man who is eating and drinking as well as King George. Good teachers use such enlivening detail to capture the fancy of their students.

A final dimension of deep understanding of the subject mater is *integration* or relatedness. In the social sciences there are many ways in which ideas or phenomena can be interrelated. I will use two types of relationships as examples: causal and thematic. Within the field of history, for instance, events and people can be integrated by looking at causal relationships between them. In contrast, events or figures can be interpreted to represent similar issues or ideas, thus providing another way of integrating historical knowledge. I discuss each relationship in turn.

Some historians claim that the study of history is the study of causes. Frequently, they look for cause by asking whys: *Why* did Roosevelt win the Election of 1932? Why did the British Empire expand in the ways that it did? *Why* does apartheid exist? But historians seldom find one answer to their question "Why?" Instead, they find multiple and competing candidates for their construction of causal explanations. Subsequently, they arrange the causes, constructing interpretations. Cause then, and the historian's interpretation of causality, are central to history. If a teacher makes the claim that she has knowledge of history, then it follows that she must be aware that questions of cause, purpose, and motive are central to historical understanding.

But the phenomena examined by historians are related in ways other than causation. Another type of integration related to the thematic or categorical relationships between ideas or phenomena. Events, ideas, and people can *represent* particular issues or phenomena or themes, and what makes them significant is their representativeness. For example, Sean

knew that James Farrell and John Steinbeck were both authors who used their fiction to showcase and protest hardships weathered by the American family during the Depression. He used this knowledge in selecting the types of literature he wanted students to read during the unit on the Depression.

Alternatively, Sean also knew that the Unemployment Relief Act, which created the Civilian Conservation Corps, represents a type of relief legislation F.D.R. pushed through Congress during the First New Deal, while the Tennessee Valley Authority Act is an example of reform legislation. Because he knew that these pieces of legislation represented different aspects of F.D.R.'s New Deal--relief versus reform--Sean selected them from the morass of acts and agencies and laws presented in the textbook because they *represented* central issues. Thus, students learned that these acts were *meaningful*, that they represented issues. They did not think of them simply as floating facts to be memorized for no particular reason. Nor did they memorize seemingly endless lists of the alphabet soup legislation of the New Deal. Sean's knowledge the subject matter allowed him to *select* the appropriate material to have students learn.

Proposition 2: History teachers should be knowledgeable about the nature of each of the disciplines that comprises the social studies. A central dilemma in the certification of social studies teachers is that most teachers are certified to teach not one, but many other subjects when they receive their social studies credential. Other curriculum areas suffer similar dilemmas. Science teachers, for example, are expected to know chemistry and physics and biology and ecology. The worst case, of course, is that of elementary certification in which a single elementary school teacher is expected to teach every subject matter to every student. Yet if we take the recent calls for reform in teacher education and certification seriously, and respond to the proclamation that teachers must know their subject matters in the kinds of ways that I have described in the previous section, then credentialing and licensing policies run counter to those claims.

In other words, if we take seriously the notion that teachers must have rich subject matter knowledge, we cannot expect that social studies teachers can or will know equally well anthropology, sociology, political science, economics, American history, world history, western European history, psychology, and any of the other subjects that are included in social studies. It is impossible for one teacher to know all of the social sciences that comprise the high school social studies curriculum in the kind of depth that I have described. Yet most social studies teachers are required to teach multiple subject matters, sometimes even in the same course. It is possible for a teacher to become certified to teach any social studies class without ever taking a course in American history. It is not unusual for new teachers to be assigned courses that they have not had since they themselves were in elementary or secondary school. Yet such current practice is certification flies in the face of our commitment to subject matter knowledge in teachers.

There are at least two solutions to the dilemma. We could call for narrowing the focus of certification within the social studies, certifying teachers to teach one subject matter, not many. Alternatively, we could continue to certify teachers for all of the social studies but require that every teacher proclaim a specialty. Teachers would be required to exhibit deep subject matter knowledge within their specialty and a more facile understanding of the other content areas they might be assigned to teach.

Among the understandings one might require on this other level might be knowledge of the similarities and differences across the social sciences, that is, what makes economics different from political science different from history different from anthropology. But this requirement cannot be fulfilled by checking to see if new teachers can recite dictionary definitions of the different social sciences. Anthropology is more than the study of human beings, sociology is more than the study of society and institutions of social order, psychology is more than the study of the self. The boundaries between the social sciences and history are fuzzy--many of the topics for debate are the same but, because disciplines of thought offer particular lenses through which to view the world, the kinds of questions that scholars ask about those topics differ across disciplines. Moreover, the methods that they use differ--both because the questions differ and because scholars from different traditions of thought value and search for varying sources of evidence and data.

Teachers need to know about those differences. It should *not* be the case that a social studies teacher believes that history is, as one novice teacher once told me, "knowing . . . the facts, all the dates. Knowing all the terms." while political science was interpretive, thematic, and explanatory (Wilson and Wineburg, 1988, p. 527). Misconceptions such as this one can have devastating effects on what a teacher chooses to do and say in a social studies class, and social studies teachers need to understand the nature of knowledge and work in each of the subjects they teach for at least two reasons.

First, although there is always the potential that teachers will learn more about the subject matters they teach over time, misconceptions about those subject matters may be obstacles to future learning. For example, in working with novice teachers we have found that beginning teachers who believed that history was fact, even when exposed to information about interpretations in history, did not recognize them for what they were (Wilson and Wineburg, 1988). In a very real sense, their ignorance closed off possible doors to future learning. Sean knew that there were certain things he didn't know about the New Deal. For example, he was not aware of alternative interpretations of F.D.R.'s leadership but his knowledge of history led him to believe that there were multiple perspectives on how good a president Roosevelt was. Consequently, he looked through his books for information about varying accounts and found them. In contrast, Fred, the teacher who believed that history was fact, would not even know to pursue this possibility. In this way, Sean's knowledge of the nature of history facilitated his continued learning. Conversely, Fred's

ignorance impeded such learning. When certifying beginning teachers, we are forced to assume that there are many things that teachers will learn from experience in classrooms. But making this assumption does not free us of the responsibility for priming them for that learning.

Another reason history teachers should know about the other subject matters that comprise the social studies is that they should have a sense of where students have come from and where they are going. Although teachers are only responsible for what their students learn in the time they work with them, teachers should not ignore the curricular experiences of their students over the years. An awareness of what the students have already covered and what they need to be prepared to learn in the future can help teachers shape not only what they present to students, but how they present the material to them. Knowing, for example, that students will be taking a course in economics in their senior year, an American history teacher can lay some foundational knowledge about the relationship between economics, politics, culture, and industry in the United States. Alternatively, teachers can introduce vocabulary that will facilitate future learning when the class discusses bank crises, stock market crashes, or the federal reserve system. Teachers who know where their students have been and where they are going are better prepared to treat those students as people who have already learned a great deal about history, and who will be learning more in the future.

But lest we assume that knowledge of history and other social sciences is sufficient for teaching, remember the brilliant historians each of us has encountered who had little capacity to teach. Knowledge of history and the other social sciences is certainly necessary to teaching but it is not sufficient. History teachers also need to know *how to teach* history. Such a complex capacity involves many types of knowledge, skill, and disposition, but in this paper I concentrate on one kind of understanding, "subject-specific pedagogical knowledge." Such understanding is the joint product of concerns about teaching, learners, and subject matter.

Subject-Specific Pedagogical Knowledge

Subject-specific pedagogical knowledge, alternatively called pedagogical content knowledge (Shulman, 1986; Shulman and Sykes, 1986; Wilson, Shulman, and Richert, 1987), is an understanding of how to teach particular subject matters to learners to meet certain goals. Subject-specific pedagogical knowledge has many dimensions. For beginning teachers, two important aspects of knowing history for the purposes of teaching include knowing how to transform the subject matter for teaching and knowing how to critically analyze and use curricular materials appropriately.

Proposition 3: History teachers should know how to transform the subject matter. Teaching history is not equivalent to knowing history for a third party, the learner, is always

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present in teaching. Good teachers know that their students have beliefs, knowledge, skills, preconceptions, and experiences that affect what they learn. Studies of learning clearly show that students are not empty vessels or blank slates which teachers fill with information. Rather, learners are active participants in the process of learning. The story one student hears and takes away from history class will be much different from the story another student hears. Teachers who believe that students do not filter, twist, construct, and re-construct the information that they are presented with are naive about the processes of learning. Just as the final listener in the party game "Telephone" receives a different message than the first, students come away from stories well told in history class with a range of understandings.

Teachers who have subject-specific pedagogical knowledge know many things about how students typically construct their understandings about the history they are taught. Such teachers know about the most common misconceptions students have about revolution, about leadership, about chronology, about government. These teachers also know what kinds of prior experience students have that can be used as springboards into discussions of new material. It is not accidental that so many teachers use the metaphor of the mother-child relationship when discussing the bonds between England and her colonies. Since most students have knowledge of mother-child relationships, teachers know they can use that knowledge in teaching them new things. However, teachers also know that students have qualitatively different conceptions of such issues, and they acknowledge that in their teaching.

This process of thinking about the subject matter and about the learner and making decisions about how best to teach can be called a process of *transformation*. In transforming the subject matter into educational experiences for students, teachers create *representations* of history (Shulman, 1987; Shulman and Sykes, 1986; Wilson, Shulman, and Richert, 1987; Wineburg and Wilson, in press). Talking about the relationship between England and the colonies in terms of a mother and child is one representation of that relationship. Other illustrations, metaphors, examples, and analogies might cast the relationship in a different light, providing yet other representations.

Sean's instruction included a number of representations. His "You Are the President" activity presented students with information about the problems that the nation suffered during the Depression in a format that required students reflect on how they might solve such dilemmas. In this way, he tried to transform historical information about the New Deal into an experience that would appeal to students and engage their thinking. In much the same way, he decided to have students argue over the question, "How new was the New Deal?" Such an activity required that students learn information that would help them develop their arguments, as well as requiring that students develop logical arguments in response to the question. By engaging students in such a task, Sean was also trying to

communicate to students the underdetermined nature of history--that the answer to the question "Was the New Deal really new?" is not an unequivocal "Yes!" or "No!" but a matter of interpretation. In both of these cases, we can see Sean struggling with transforming information about the Depression and the New Deal into instructional representations of the material. As he did so, his concerns for content--what he wanted students to learn about history, students--what they already knew or believed or valued, and purposes--teaching students to develop arguments, use materials, and to appreciate the value of knowledge of the past, all contribute to his pedagogical reasoning (Wilson, 1988).

Teachers are responsible for the learning of many students who have backgrounds, interests, experiences, and values that may differ substantially from those of the teacher. To make connections, teachers must think about multiple ways to present, communicate, and engage students in the subject matter. They must have a repertoire of representations, for all students do not have the same prior experiences and will not respond equally to a single representation. In response to students' misunderstandings or lack of engagement, teachers must reconsider their explanations and invent new examples, illustrations, and metaphors. While a single representation may have led to a teacher's personal and private understanding, teaching is a public activity requiring that ideas and understandings that historians can leave buried in the mind's recesses be made public. Historians work alone in libraries and dens, reading diaries and tax records--silent companions. Teachers work in classrooms with students who are anything but silent. Teachers must find ways to present publicly those ideas to learners so they may construct their own understandings. Historians can write one explanation. Teachers must generate multiple representations in response to students' questions and concerns. Sean is beginning to accumulate a repertoire--the mini-lectures, the large-group discussions and questioning, the debate, the "You Are the President" activity, the small group work with photographs, music, and literature--of representations of the Depression and New Deal. As he acquires more teaching experience, Sean will alter, enrich, elaborate, or cast off these representations, as well as others that he develops over time.

We cannot expect beginning teachers to have the wealth of representations that an experienced teacher may have accumulated over many years of practice. Nor can we expect their representations to be fully developed or finely tuned. However, it is essential that beginning teachers have learned to think about representing history to their students. That is, they need to be predisposed toward transforming the subject matter in ways that capitalize on what students already know and believe. They also need to have the skills and understandings necessary to generate such representations and to evaluate representations that they acquire from other sources, such as teachers or curriculum materials. Sean, for example, needs to understand the purposes for small-group instruction, as well as different models for such teaching, if he is to develop and subsequently evaluate representations that

involve small group work. Alternatively, he needs to understand how to learn about students' misconceptions about the subject matter if he is to integrate such knowledge into his teaching.

Proposition 5: History teachers should know how to evaluate critically curricular materials. I make this claim for a very simple reason. It has been well documented that the textbook remains a central teaching tool and source of information for social studies teachers (Shaver, Davis, and Helburn, 1979 a, 1979 b). Unfortunately, analyses of social studies textbooks, like those done by FitzGerald (1979) and Gagnon (1987, 1988), suggest that the history represented in textbooks bears little relation to other histories. The information presented in textbooks is often oversimplified, seldom current, and sometimes false.

If textbooks do not present truth, if some of them present pablum instead of history, teachers who treat textbooks as knowledge run the risk of teaching untruths to their students. I highlight teachers' use of textbooks here as an illustration of the larger issue: Much of what finds its way into high school history classes, either in the form of textbooks or other curricular materials, is not the subject matter to be taught. It is history revised, to paraphrase FitzGerald. Teachers must know how to appraise textbooks critically, using them as resources, not as the sole determinants of content or pedagogy.

I will revisit the example of Jamestown to make this point. Todd and Curti (1986), authors of one of the most popular textbook in the United States at this time, provide the following depiction of Jamestown:

> **Better times at Jamestown.** Slowly, after 1610, the conditions [in Jamestown] began to improve. Much to everyone's surprise, tobacco saved the colony. . . . By 1619 there were more than 1,000 colonists in Virginia and most were raising tobacco. . . . The directors of the London Company, encouraged by Virginia's growing prosperity, sent out hundreds of new settlers. Some of them started an ironworks on the James River. Others planted olive trees and laid out vineyards, but most of the newcomers cleared a piece of land and began to grow tobacco.
>
> Then disaster struck. Nearby Indians had become alarmed at the rapid growth of the colony. On March 22, 1622, Indians attacked the outlying farmhouses, killed 347 settlers, including John Rolfe, and burned most of the buildings. (pp. 24-25)

Textbook authors *have* to simplify American history; it would be impossible to provide all of the information and current thought that exists about the history of the United States in one book, even if there were several volumes. The account of Jamestown that Todd and Curti present is accurate--after 1610, conditions *did* begin to improve, the population of the colony *did* grow, most of the colonists *were* raising tobacco. But what might a student "learn" from such an account?

For one, it is possible that a student would come away from reading this text with the idea that tobacco was the saviour of Jamestown. That conclusion is, although partially correct, an oversimplification. A teacher who knew that colonists were so busy putting all of their resources into tobacco planting for the profit that they failed to grow enough crops to feed the colony would be able to and might choose to help students understand that, while tobacco was a saviour in some ways, tobacco was the devil in others.

A student might also "learn" that the Indians contributed substantially to the death rate of colonists; nearly 350 people in a colony of about 1000 (the only population information they have) is a substantial percentage. But a teacher who knew that 3,570 settlers were sent to the colony between 1619 and 1622 and that the population of Jamestown in 1622 was about 700 (which is what it was in 1619 prior to the importation of these settlers), would also know that 3500 settlers disappeared. If that teacher also knew that no significant portion of them returned to England or migrated to other colonies, and that the Indians killed 347 of them in the 1622 incident, she would know that 3000 colonists died in some other way over that time span. The incident reported in the text accounts for only ten percent of the total deaths. Teachers who knew such things might choose to show students that Indians were not the only threat to the lives of early Virginians. Rather, as we learned earlier, the colonists themselves contributed to the population problems of the early years of Jamestown.

Clearly, teachers' knowledge of subject matter and subject-specific pedagogy are critical to their ability to evaluate textbooks. Teachers with little subject matter knowledge, for example, might become victims of their limited sources. Unaware of the problematic nature of the content of history texts, they may choose to teach what they have read as truth. Novices in the subject matter, that is, may not be able to differentiate when a textbook account is accurate and when it is not.

Sean was able to use the textbook wisely in his teaching because he knew several things. He knew that textbooks are necessarily sketchy in the coverage they provide history since the scope of the curriculum is so broad. His knowledge of historical knowledge--that it is interpretative, for example--made him question the textbook's interpretation of F.D.R. since the authors seemed to only have glowing things to say about Roosevelt. Moreover, his knowledge that the New Deal was more than a legislative package made him critical of the fact that the textbook presented only the political and economic history of the period, paying scant attention to labor, social, cultural, and intellectual history. Thus, Sean's knowledge of both history and of the problems with curriculum enabled him to use the textbook as a resource instead of treating it as the sole authority on historical knowledge in his teaching.

Because textbooks are a mainstay of many secondary school classrooms and because we cannot expect social studies teachers to have all the subject matter knowledge, pedagogical knowledge, or subject-specific pedagogical knowledge they need in order to

teach effectively, teachers like Sean must also be equipped to be defensive readers of their texts and other materials, constantly looking to other sources for information that will sometimes confirm, sometimes contradict, but always enrich their understanding of the subject matter to be taught.

I close this discussion with a warning. It is dangerous and presumptuous to assume that the types of knowledge--deep subject matter knowledge and subject-specific pedagogical knowledge--described here are the result of the completion of an undergraduate degree in history and a teacher education program. Many undergraduates never learn to think about history in the rich, deep, and flexible ways that I have described. That kind of knowledge cannot be acquired by taking a series of survey courses nor is it the result of the kind of teaching documented by Boyer (1987). Yet many states have responded to the claim that teachers need to have more content knowledge simply by increasing the number of required courses teachers take in the content areas that they intend to teach. This is a shortsighted and superficial response to a substantive and substantial problem.

Likewise, the pedagogical reasoning required to generate instructional representations and the subject-specific knowledge needed for teaching are not results of all teacher education programs. For any set of claims we make about what teachers need to know, we must also consider when and where they acquire these understandings. In the case of history teaching, the picture is grim.

Conclusion[15]

The current practice of teaching history at school and university exerts a powerful influence on future generations of history teachers. Our future teachers have few models of good teaching to use as touchstones and the certification of beginning teacher's knowledge alone is not likely to be a sufficient counterforce, even if it were substantially reformed. Tomorrow's teachers are today's students, sitting in school and university classrooms where much pedestrian teaching takes place. The schooling system feeds itself, maintains itself. What is required is not learning from experience, but breaks with experience--the experience of mediocre teaching that too often greets the student. An agenda to improve the quality of history teaching and learning for teachers and students alike must have two aspects.

First, the teaching of history in our schools and universities must be honored and improved. At the elementary and secondary level this means strengthening teachers' connections to and identification with history. At the university level, this means strengthening historians' connections to and identification with teaching. If such symmetry is not pursued, then little progress will be made. At issue is whether historians and history

[15] The ideas, and many of the words, in this conclusion are borrowed from the work that I have done with Gary Sykes on the certification of history teachers, cf. Wilson and Sykes, in press.

teachers form one or two professions. Here too the tendency is to pull apart that which is better joined--the school to the university, teaching to scholarship.

The best history teachers in our schools know a great deal about teaching. They can profit from connection to historical scholarship. Historians stay abreast and contribute to research, but typically fail to learn much about teaching. The first aspect of reform, then, must encourage status-equalizing opportunities for historians and history teachers to learn from one another, so that research and teaching may be mutually informative and educative, so that a common professional identity may begin to form.

The second aspect concerns the formal preparation of history teachers, encompassing the standards framework, the university course work, and the structure of opportunity for practice and induction in the schools. Teacher educators also belong within the profession of history teachers. They will be responsible for much of the research on teaching and learning history, and should work closely with colleagues in history departments on the preparation of teachers and the improvement of teaching. This means establishing closer collaboration across departments within the university and between universities and schools. Rather than regarding the university curriculum as a zero-sum contest for control of credit hours, historians and history educators should work together to strengthen the intellectual content and the integration of course work for prospective teachers.

State standards should likewise begin to focus on pedagogical and curricular knowledge of history. A promising lead in this regard is the emerging work of the National Board for Professional Teaching Standards. This body was established in 1987 to develop procedures for the voluntary certification of teachers.[16] Research and development work underway on innovative assessments has begun to suggest promising approaches that states might draw upon, and the Educational Testing Service has already announced a multiyear effort to reform the National Teachers Examination to accommodate these emerging developments. So it appears that promising changes are getting underway, changes that will more centrally emphasize deep knowledge of subject matter and subject-specific pedagogical knowledge.

States also should press forward with plans to create induction experiences for beginning teachers. A sensible approach might involve providing the first-year history teacher with a reduced load, assistance from a mentor teacher, and a continuing seminar at a nearby university. Such structural arrangements may be set in the context of extended teacher education and/or licensure requirements, for the supervision of initial practice provides a performance base for evaluation. Here too, however, standards and criteria must

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[16]The National Board for Professional Teaching Standards is comprised of 65 teachers and teacher advocates. This group is engaged in a national and comprehensive reform effort that involves the certification of teachers using alternative and innovative assessments, as well as calling for the changes in schools and schooling necessary to support accomplished teaching.

emphasize subject matter teaching in addition to generic teaching skills. Beginning teachers understandably are concerned with the management aspects of teaching, but evidence also suggests this preoccupation can drive out attention to the teaching of subjects. States can begin to support teachers in ways that will correct this imbalance.

When we consider what beginning teachers need to know, we must consider a multitude of contexts that affect the answer to that question. We must consider what knowledge about history and about teaching beginning teachers have been exposed to; we must consider when and how beginning teachers' knowledge is assessed; we must consider the very real demands of schooling; and we must consider our conceptions of the process of learning to teach. Policymakers concerned with improving one piece of the teaching puzzle--the knowledge of beginning history teachers--who ignore such considerations of these other pieces ensure the demise of their own efforts.

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SOCIAL SCIENCE KNOWLEDGE AND CITIZENSHIP EDUCATION

James A. Banks[17]

In her carefully conceptualized, interesting, and well crafted paper, Wilson identifies and describes two main types of knowledge that history teachers need: (a) subject matter knowledge and (b) subject-matter specific pedagogical knowledge. With the use of a vivid case study and rich examples, she successfully illustrates the importance of these two forms of knowledge for effective social studies teachers. Because her paper is successful in attaining its major goals, my comments are designed primarily to extend the scope of her paper by focusing on issues related to the knowledge of social studies teachers that she discusses only briefly, and to present different perspectives on other issues that she discusses in more depth.

What Should Students Learn?

In a potentially significant but overly brief section of her paper, "What Should Students Learn in History Class?" Wilson discusses the various debates over goals and rationales in social studies education--for example, whether the social studies should focus on the social sciences, value education, citizenship transmission, or reflective citizenship. She devotes little analytical attention to the serious debates over rationales and goals in social studies education and, perhaps unwittingly, dismisses a rich, historical, and sophisticated body of literature in social studies education that deals with rationales and goals (Atwood, 1982; Barr, Barth, and Shermis, 1977; Engle, 1960; Hunt and Metcalf, 1955; Shaver, 1967, 1977). She calls these debates "unproductive illusions, false dichotomies in a sense" (p. 138). She reaches this conclusion because she believes that these debates over conflicting rationales and conceptions can be resolved by the implementation of an eclectic version of the social studies that incorporates a number of important curriculum elements, characteristics, and goals. She writes, "Those goals are not antithetical. Rather, they may all be different ways of teaching about the same set of concerns" (p. 138).

The succinct treatment of conflicting conceptions and rationales in social studies education is a serious problem in Wilson's paper. This is the case not only because a knowledge of the conflicting goals and conceptions in social studies education is an important kind of pedagogical content knowledge that teachers need in order to reflectively choose a rationale to guide their instructional decisions, but also because teachers who have

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an eclectic rationale for social studies teaching are rarely effective in the classroom. These teachers are like the jockeys who try to run their horses in several directions at the same time. Effective social studies teachers must embrace and reflectively derive a clear, coherent, and consistent rationale for teaching (Goldmark, 1968; Newmann, 1975, 1977). Confusion about goals and attempts to teach using an eclectic rationale often results in the kind of deadly, boring and nonreflective social studies teaching that Wilson and other researchers have described and documented (Goodlad, 1984; Shaver, Davis, and Helburn, 1979). Newmann (1977) states that a comprehensive rationale should state positions in "seven problem areas: curriculum goals, nature of learning, definition of community, citizenship and other goals of schooling, schools and other social agencies, authenticity, and diversity" (p. 11).

An example using two hypothetical teachers who embrace different and conflicting rationales for social studies teaching will illustrate my point. Ms. Hinkle is a high school social studies teacher who endorses a "citizenship transmission" rationale for teaching (Barr, Barth, and Shermis, 1977). She believes that the primary goal of the social studies should be to help students inculcate the "right" values and historical facts so that they will become loyal and unquestioning citizens of the nation-state. Such students will become deeply loyal but will not question national policies and decisions. They will view questioning the national government as unpatriotic.

In her teaching of history, Ms. Hinkle is likely to emphasize the glorious aspects of the U.S. past, no matter how much subject-matter knowledge she has mastered. Ms. Hinkle may have mastered as much subject-matter knowledge as Wilson thinks is desirable, yet it is highly unlikely that she will become a reflective and creative teacher like Sean. She will mediate the subject-matter knowledge she has acquired when teaching. Her selection and presentation of this knowledge will reflect the vision of the kind of citizens she wants to socialize--namely, students who are nonreflectively loyal to the nation and who accept, without question, the "official" version of the United States past, present, and future. Such citizens will engage in adulation of the nation-state without reflection.

Neither subject-matter nor pedagogical knowledge is sufficient to substantially change the way Ms. Hinkle teaches. She needs to examine alternative and conflicting conceptions of social studies education, to analyze their assumptions and purposes, and to reflectively derive a rationale for social studies teaching that is coherent and consistent. Only then will she be able to select social science content, methods, and teaching strategies in a deliberate and reflective way. Knowledge of conflicting rationales, goals, and visions in social studies education, and the opportunity to reflectively derive a clarified philosophical position with regard to the goals and purposes of social studies education, is essential in a teacher education program and a prerequisite to reforming social studies teaching in the nation's schools. A teacher's vision, goals, and purposes for teaching cogently influence how she

selects and interprets social science knowledge, the knowledge she selects to teach, the knowledge she chooses not to teach, how she mediates and interprets knowledge (Parker, 1987), and how she interacts with students when discussing the knowledge she teaches. The selection and interpretation of knowledge is essential in social studies teaching.

Ms. Hinkle endorses a citizenship transmission conception of social studies education. Another teacher, Ms. Cortes, endorses a rationale of social studies education that we may call "reflective citizenship." She believes that the major goal of social studies education should be to create reflective citizens who can and will actively participate in the reformation of society to make it more just and consistent with the ideals Myrdal described as American Creed values (Myrdal, 1944). Helping students to hear and understand the voices of women, people of color, and workers will be much more important to Ms. Cortes than to Ms. Hinkle. Ms. Cortes, unlike Ms. Hinkle, is likely to view historical literacy "as a struggle for voice." In this conception of historical literacy,

> All students will deal with the fact that their voices differ from one another's, from their teachers', from their authors'. All learners will somehow cope with the issue of translating their many voices, and in the process they will join in creating culture (and history), not simply receiving it. (Starrs, 1988)

Social Studies Versus History

The bulk of Wilson's paper is devoted to a discussion of the knowledge needed by effective history teachers. I am going to take what is perhaps an iconoclastic view at a conference on the knowledge base of teaching. I think we ought to educate social studies teachers rather than history teachers. History and the other social sciences are distinguished from the social studies in several important ways. We should not make the mistake, in our quest to infuse the social studies curriculum with sound historical knowledge, of assuming that the social studies is the social sciences simplified for pedagogical purposes (Shaver, 1967; Wesley, 1937). We have often made this mistake in the past and have created social studies curricula that do not deal with the important concerns of students and of society.

The social sciences and the social studies differ significantly in aim or purpose. The main goal of the social sciences is to build theoretical knowledge (Merton, 1968; Zetterberg, 1965). Consequently, the social scientist devotes her attention to the building of empirical propositions. Homans (1967) states that the major aim of any science, including the social sciences, is discovery and explanation:

> Any science has two main jobs to do: discovery and explanation. By the first we judge whether it is a science; by the second, how successful a science it is. Discovery is the job of stating and testing more or less general relationships between properties of nature. (p. 7)

Homans contends that history is a science like the other behavioral sciences, not because of its results but because of its aims.

While the aim of the social sciences is to build theory that explains human behavior, the major aim of the social studies is to prepare reflective citizens who can participate effectively in public discourse and deliberations and who can act to improve society and make it more consistent with humane values, such as equality, justice. and human dignity. The aim of the social scientist is achieved when she explains and predicts behavior. However, this is where the aim of the social studies educator begins. The social studies must help students to synthesize and use the knowledge derived by social scientists to make reflective and humane decisions (Banks with Clegg, 1985; Engle, 1960; Shaver, 1967). Decision making and citizen action is the chief aim of social studies education. The main components of decision making are scientific knowledge, value analysis and clarification, and the synthesis of knowledge and values. Consequently, the analysis of moral and public issues is an essential component of social studies education (Oliver and Shaver, 1966). An important kind of pedagogical knowledge that social studies teachers need is knowledge of theories of moral development, value-inquiry strategies, and decision-making models and techniques. They also need to know how social science knowledge can be used to help solve important public problems faced by citizens in a democratic nation-state.

Social science knowledge is an important part of an effective social studies curriculum. However, the ways in which social science knowledge is interrelated and used in interdisciplinary ways to inform effective decisions and citizen action should be emphasized in social studies teaching. Homans (1967) states that the social sciences are a single science. He states, "These sciences are in fact a single science. They share the same subject matter--the behavior of men. And they employ, without always admitting it, the same body of general explanatory principles" (p. 3). The inventory of scientific findings compiled by Berelson and Steiner (1964) supports Homans's claim.

Teachers need knowledge of the ways in which the social sciences are interrelated and should be able to view issues, concepts, and problems in an interdisciplinary way. Teachers also need an interdisciplinary orientation to the social sciences because disciplinary boundaries are often blurred in the real world of the schools as units are taught that include insights and perspectives from several different disciplines. Sensitive to the nature of the social sciences and to the real world of the schools, Wilson wisely devotes an important part of her paper to the need for history teachers to have some knowledge of each of the social and behavioral sciences (Proposition 2, pp. 147-149).

The Limitations of the Documentary Record

To become effective social studies teachers, teachers must understand the way in which knowledge is constructed in history and the other social sciences, how knowledge reflects the social context in which it is created, and why significant knowledge gaps exist in the history of some groups, such as African American women, child laborers, and migrant workers. Effective teachers must understand, and must help their students to understand, what we do not know as well as what we know about the past. Much of the history of Indians and African Americans, and especially Indian and African American women, is lost, perhaps forever. Teachers need to understand that important aspects of some people's history is lost, as well as why there are significant gaps in the documentary record. Case studies can be used to illustrate aspects of history that are lost, strayed, or stolen. We have rich accounts of the Lewis and Clark expedition from their diaries, but only sketchy information about York, the African American who accompanied them and who, as far as can be determined, played an important role in the success of the Lewis and Clark expedition (Logan and Winston, 1982).

African American historians in Washington state are trying to construct the history of Marcus Lopez, believed to be the first Black to settle in the Pacific Northwest. However, they have been able to construct only a sketchy portrait of this early African American pioneer. Lerner (1972), who has done pioneering research on the history of women, points out that the "limitations of the available documentary record . . . result in omissions and a middle class bias" (p. xxii).Rich historical documents exist describing the life of the rich, the powerful, and those who won wars and battles. However, the life of the poor, the victimized, and the vanquished are as voiceless in historical documents as they are in contemporary life. If teachers and their students are keenly aware of the limitations of historical and social science knowledge they will be able to use it more effectively to make sound decisions on public policy issues.

We should be educating social studies rather than history teachers for several reasons that are related to (a) the nature of the social science disciplines, (b) the goals and purposes of social studies education in a democratic society, and (c) the realities of schoolteaching. I discuss each of these reasons below.

The Social Science Disciplines

The social science disciplines are interdisciplinary rather than separate and discrete. Increasingly, historians are using concepts from disciplines such as sociology, psychology, and anthropology. Concepts from these disciplines have enriched the historical study of women (Cott and Degler, 1987), people of color (Gutman, 1976) and workers (Terkel, 1972). History has always been highly interdisciplinary. Traditional history emphasized concepts from politics, political science, economics, and the military. The social science disciplines do

not consist of unique content, but are formalized and unique ways to view and understand human behavior. To gain a comprehensive understanding of human behavior and of problems and issues in society, students must be helped to view them from the perspectives of several social science disciplines, as well as from the perspectives of philosophy and the arts (Engle and Ochoa, 1988). To view issues and problems from the perspective of a single discipline will result in only a partial understanding of human behavior.

The Goals and Purposes of the Social Studies

The major aim of the social studies should be to help students become reflective decision-makers and civic actors who can and will participate in the transformation of society--that is to make it more democratic and just (Banks, 1988; Banks with Clegg, 1987). To make reflective decisions on and to take effective action related to complex social issues and problems such as sexism, racism, nuclear proliferation, and homelessness, students must view these problems from the perspectives of different disciplines, as well as from the perspectives of the groups who are the main victims of these problems, such as women, people of color, poor people, and people who are powerless and marginalized (Banks and Banks, 1989). Disciplines such as anthropology and sociology have a better record than history (and political science) for giving voice to voiceless groups such as women, African Americans, and workers. While all disciplines, including anthropology and sociology, reflect the ideologies and perspectives of the powerful groups within a society (Berger and Luckmann, 1966; Mannheim, 1936), history has been and is used more frequently than anthropology and sociology by dominant groups to reinforce their hegemony and to make powerless groups docile and content with the status quo. In recent years, both the Soviet Union and Japan have rewritten their history textbooks to make them more congruent with the prevailing views and ideologies of dominant and powerful groups in society.

It is interesting to speculate why dominant groups frequently use history, rather than anthropology or sociology, to reinforce prevailing political and economic ideologies. This may result in part from the nature of inquiry in history and from the way in which it evolved. History, especially in its infancy, often told the stories of great nations by focusing on the leaders and military battles that made the nation great. Heredotus, a Greek historian who lived in the fifth century BC, wrote a history of the Greco-Persian Wars, the first important European historical narrative of the ancient world. The story of the conquered, the victimized, and the common people is rarely told in the narrative histories that document the growth of expanding empires.

Anthropologists, in contrast to historians, were deeply concerned with the stories and cultures of common people and ethnic groups when their discipline emerged in the United States. Leading U.S. anthropologists, such as Boas, Benedict, and Mead, were also interested in using anthropological research as an antidote to the racism that was rampant

during the World War II period (Benedict, 1941; Pelto and Muessig, 1980). Race relations research was also of paramount concern to sociologists such as Robert E. Park and his colleagues in the "Chicago School" of sociology at the University of Chicago during the 1930s and 1940s (Lyman, 1972). Early courses in Black studies drew heavily upon concepts and data from sociology when the Black Studies movement gained momentum in the 1960s and 1970s. The only course offered on many U.S. college and university campuses in the early 1950s and 1960s that dealt with race relations was usually taught in the department of sociology. Although Black historians such as George Washington William, W. E. B. DuBois, Carter G. Woodson, and John Hope Franklin had created rich scholarship in African American history, it had been largely ignored by White, mainstream historians until the civil rights movement of the 1960s and 1970s (Meier and Rudwick, 1986).

Because of the way that history is often used and misused by dominant groups within a society, we ought to be somewhat skeptical of the strident call by conservative popular writers and historians for more history in the schools, and particularly for more factual history. This call has been made by such popular writers as Hirsch (1987) and Ravitch and Finn (1987). Rarely do these writers address such issues as the perspectives from which "more history" will be told, its purposes, and whose interests will be served by the teaching of more factual history in the schools. Aronowitz and Giroux (1988), in a thoughtful and important review of the books by Bloom (1987) and Hirsch (1987), suggest that these books are part of a neoconservative political scheme that perpetuates a "public philosophy informed by a crippling ethnocentrism and a contempt for the language and social relations fundamental to the ideas of a democratic society" (p. 194). They also point out that the neoconservative critics of the school curriculum

> espouse a view of culture removed from the trappings of power, conflict, and struggle, and in doing so . . . attempt to legitimate a view of learning and literacy that not only marginalizes the voices, languages, and cultures of subordinate groups but also degrades teaching and learning to the practice of implementation and mastery. (p. 183)

The knowledge in the social studies curriculum should liberate and empower students rather than contribute to their victimization and oppression. A social studies curriculum that includes content, insights, concepts and perspectives from a range of disciplines is more likely to help students become effective civic actors and decision makers than a curriculum that focuses heavily on history, especially on facts and historical trivia. Historical knowledge taught in the schools should be enriched with concepts from the other social sciences, such as anthropology and sociology. Concepts from the behavioral sciences will enable students to better understand the experiences and voices of groups that school history often neglects, such as women, people of color, and workers.

The Realities of Schools

Schools are not organized and do not function in a way that makes it possible for teachers to be narrow disciplinary specialists and experts. When I was teaching fifth grade at the Francis W. Parker School in Chicago we planned and implemented an interdisciplinary curriculum. This interdisciplinary curriculum framework resulted in effective and stimulating teaching and learning. Interdisciplinary teaching often occurs at the elementary level, but less frequently at the high school level because many secondary teachers view themselves as history or political science teachers rather than as social studies teachers.

Many high school teachers try to maintain tight disciplinary identities and affiliations even though such affiliations are inconsistent with the culture of the public schools. The disciplinary identifications of social studies teachers may partially explain why such a small percentage of them are members of the National Council for the Social Studies, compared to the much larger percentage of English and language arts teachers who are members of the National Council for Teachers of English. Disciplinary divisions and identities have made it difficult for social studies teachers to unite and to speak professionally with one voice.

The way we educate social studies teachers contributes to the disciplinary Balkanization among them. In the next and final part of this paper, I will briefly describe a way to educate social studies teachers that will help them to attain broader disciplinary perspectives as well as contribute to the weakening of disciplinary identifications and boundaries. I perceive such boundaries as a negative influence on effective social studies teaching and learning. We need to educate teachers in a way that maintains the integrity of the specific disciplines, yet helps them to gain the knowledge and insights needed to teach school subjects in an interdisciplinary way.

A Thematic Approach to Educating Social Studies Teachers

We can help social studies teachers to acquire the interdisciplinary knowledge, skills, and attitudes needed to implement a decision-making-focused social studies curriculum by requiring them to participate in a yearlong interdisciplinary seminar that focuses on enduring social issues and problems. The issues selected for study should be ones that have been of concern to humans in the past, that are of concern today, and that will be important concerns in the future. The specific issues chosen for study should be selected by an interdisciplinary team that will participate in teaching the seminar and by the education faculty involved in the teacher education program. While the students will study the structure of the major social science disciplines (i.e., their key concepts, theories, and research methods), the focus of the seminar will be on how each of the social science

disciplines can contribute to the understanding and to the solution of enduring human problems and issues. The roles that citizens in a democratic nation-state can and should take to help solve these problems will also be highlighted. The interdisciplinary seminar would be team taught by a historian, a sociologist, an anthropologist, a philosopher, and a literature specialist. The seminar might focus on issues such as these:

1. The quest for freedom
2. Leadership and social change
3. The development, use, and control of technology
4. Immigration, migration, and population change
5. Peoplehood, cultural identity, and nationalism
6. Magic, science, and religion: The quest for explanation
7. Cooperation and conflict in human societies.

Summary

In this paper, I have tried to extend the scope of Wilson's paper by discussing in more detail points she treated briefly and to present a different perspective on several of the important issues she raises. An essential kind of pedagogical content knowledge teachers need to acquire is knowledge of the conflicting conceptions, rationales, and aims in social studies education. They also need an opportunity to examine these conflicting visions and rationales in a critical and probing way and to reflectively derive a coherent and consistent rationale that can guide their selection of goals, content, and teaching strategies.

I contend that the main goal of the social studies should be to help students acquire the knowledge, attitudes, and skills needed to make reflective public decisions and to participate effectively in the reformation of society to make it more consistent with the nation's idealized values--namely, the American Creed. Such citizens can best be developed by teachers who are educated to be social studies teachers rather than history teachers. Social studies teachers should be educated in a way that enables them to acquire an in-depth understanding of the structure of the social sciences and of how social science knowledge can be used to improve the human condition. A social studies teacher education program should also help teachers to become sensitive to the ways in which social science knowledge has been and often is used to reinforce dominant group hegemony, ideologies and institutions. I am proposing that an important component of the education of social studies teachers consist of a yearlong interdisciplinary seminar that examines a series of persistent and enduring social issues and problems. Concepts, insights, and understandings from a wide range of disciplines must be brought to bear on human problems in order to educate students who have the knowledge, will, and commitment to help make our nation and world more humane.

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KNOWLEDGE FOR TEACHING HISTORY

Catherine Cornbleth[18]

Let me begin with a simple but sensible premise: Anyone can teach history--poorly. What teachers need to know in order to teach history well depends on what kind of teachers and history teaching you want. If you want a teacher who will follow a prescribed course of study, textbook and teacher's guide, or instructional package, that teacher needs to know something different--and probably less--than the teacher who uses his or her knowledge of history, students, and classroom teaching and learning to adapt or design and carry out a history program that is both intellectually rich and meaningful to students, one that fosters thinking about history and thinking historically, not merely remembering some past events. Thought--critical, creative, reflective--cannot be planned or packaged effectively; it cannot be made teacher- or student-proof (Cornbleth, 1985b).

In the first instance, the teacher who follows someone else's plans needs some knowledge of history and classroom teaching, but primarily he or she needs management knowledge and skill and the disposition to be an effective manager. Assuming the plans to be followed are good ones (or at least reasonable in terms of the history and students to be taught), this teacher can be successful--as long as no substantial obstacles are encountered. This is somewhat akin to memorizing one's part in a play (or presentation at a conference) without having a sense of one's role or the play as a whole. It "works" as long as you remember your lines and follow your roles or script. But, if you forget a line or two, or someone else does, you're lost--speechless--usually unable to improvise. It's awkward at best. In contrast, with a sense of one's role and the play as a whole--with comprehension and judgment--you can improvise and improvise well; informed improvisation "works."

Given the complexity and variability of classroom life, my preference, not surprisingly, is for this latter kind of teacher--not the manager or technician but the reflective practitioner (Schon, 1983, 1987) or thoughtful expert. Becoming this kind of teacher requires considerable knowledge and time--time to act on one's knowledge, reflect on that action, gain further knowledge, and revise future practice. My point here is that we distinguish the knowledge needed by and our expectations for beginning teachers from that of advanced or expert teachers. In making such a distinction, it is important *not* to assume that the beginning teacher will be a manager who, somehow over time, will become a reflective practitioner. That transition is very difficult if not impossible to accomplish. Instead, the

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beginning teacher might be expected to be more knowledgeable and thoughtful about some aspects of history teaching than others and to expand his or her repertoire gradually.

A second distinction important to our consideration here is that between teacher knowledge and *knowledge-in-use*. Teacher knowledge is what the teacher knows, in this case about history and teaching history. It includes implicit or tacit knowledge as well as explicit or articulable knowledge from various sources. It includes declarative or propositional knowledge "that" and procedural knowledge "how" or "how to." Knowledge that broad interpretation of the elastic clause of the Constitution has greatly increased Congressional powers is an example of declarative or propositional knowledge. Knowledge of how to communicate the meaning of the elastic clause in language and examples that 11th graders understand is an example of procedural knowledge. Knowledge that less than 25 years separated U.S. entrance into the Spanish-American War, World War I, and World War II (and the Korean and Vietnam Wars) is an example of declarative or propositional knowledge. Knowledge of how to construct a time line and how to explain time-line construction to 11th graders is an example of procedural knowledge.

Teacher knowledge tends to be the focus of teacher education and assessment efforts. If our concern is with student learning or opportunity to learn, however, at least as much attention ought to be given to teacher knowledge-in-use in classroom teaching. Teacher knowledge-in-use can be seen as a subset of teacher knowledge. It is that knowledge, broadly defined (to include what others might distinguish as skills and dispositions, attitudes, or values), actually made available to students. More specifically, knowledge-in-use refers to the selection, organization, and treatment of knowledge that the teacher makes available to students.

The knowledge that teachers select to make available to students, purposefully or otherwise, is not limited to subject matter. It also includes knowledge about the world, appropriate behavior, and the students themselves. It can be presented directly by the teacher (orally or on the chalkboard, transparencies, or handouts) or through textbooks and other materials or media. For example, after asking students to read the textbook synopsis of the deliberations of the Continental Congress leading to the adoption of the Declaration of Independence, one history teacher might review the events cited in the text while a second might elaborate on the dispute over the (deleted) section abolishing slavery, and a third might add anecdotes about Benjamin Franklin.

Knowledge organization refers to relationships or links that are made explicit among facts, concepts, principles or generalizations, and other forms of knowledge--or among events, people, ideas, and political, economic, social, and geographic conditions. For example, specific cases, instances, or events could be presented individually or as examples of a concept; the American, French, and Russian Revolutions could be presented separately or as examples of the concept of revolution.

Knowledge treatment has two aspects, one dealing with the nature of knowledge and the other dealing with the representation or transformation of knowledge to make it understandable to students. Historical knowledge can be treated as certain or tentative, as revealed or created. This aspect of treatment carries important messages about the nature of history and of knowledge more generally. Representation or transformation refers to the descriptions, explanations, examples, analogies, and so forth that teachers use to help students understand history.

Evidence from field studies conducted in history and social studies classes (e.g., McNeil, 1986) indicates that teachers' selection, organization, and treatment of knowledge is influenced by several factors. Teachers' knowledge-in-use is influenced not only by (a) what they know about history and teaching history, but also by (b) individual factors such as general world knowledge and their goals and priorities in the teaching situation, (c) social factors such as community expectations and proscriptions, and (d) structural or organizational factors such as time schedules, mandated tests, and peer pressures. This brief overview of factors shaping knowledge-in-use should not be taken to mean that teachers are mere pawns of social and structural forces. Teachers and their knowledge clearly are important. My point is that knowledge-in-use is a function of the dynamic interplay among individual, social, and structural forces, not simply a matter of what or how much teachers know.

If my distinction between teacher knowledge and knowledge-in-use and my argument for more attention to knowledge-in-use makes sense, several implications follow. One is that we need to learn more about teachers' knowledge-in-use and the factors that influence it. (At the State University of New York at Buffalo, we are undertaking such a project with clinical faculty from two Buffalo area school districts.) A second is that teacher assessment should attend to knowledge-in-use, not just teacher knowledge. A third is that teacher education introduce teachers to the concept of knowledge-in-use and the factors likely to influence it so that they might be better able to purposefully shape their knowledge-in-use instead of being swept along by unseen or unknown "forces." In other words, teacher knowledge should include knowledge of knowledge-in-use. (See Figure 1.)

The remainder of my comments here assume the teacher as thoughtful expert and the priority of knowledge-in-use--and focus on the selection, organization, and treatment of knowledge for teaching history in ways that are intellectually rich and meaningful to students.

Knowledge Selection and Organization

I treat knowledge selection and organization together because they are interdependent. What knowledge is selected influences possible organizations of knowledge. The expectation of knowledge organization guides knowledge selection. Selection is inevitable; there is just too much that could be taught and learned in the time available.

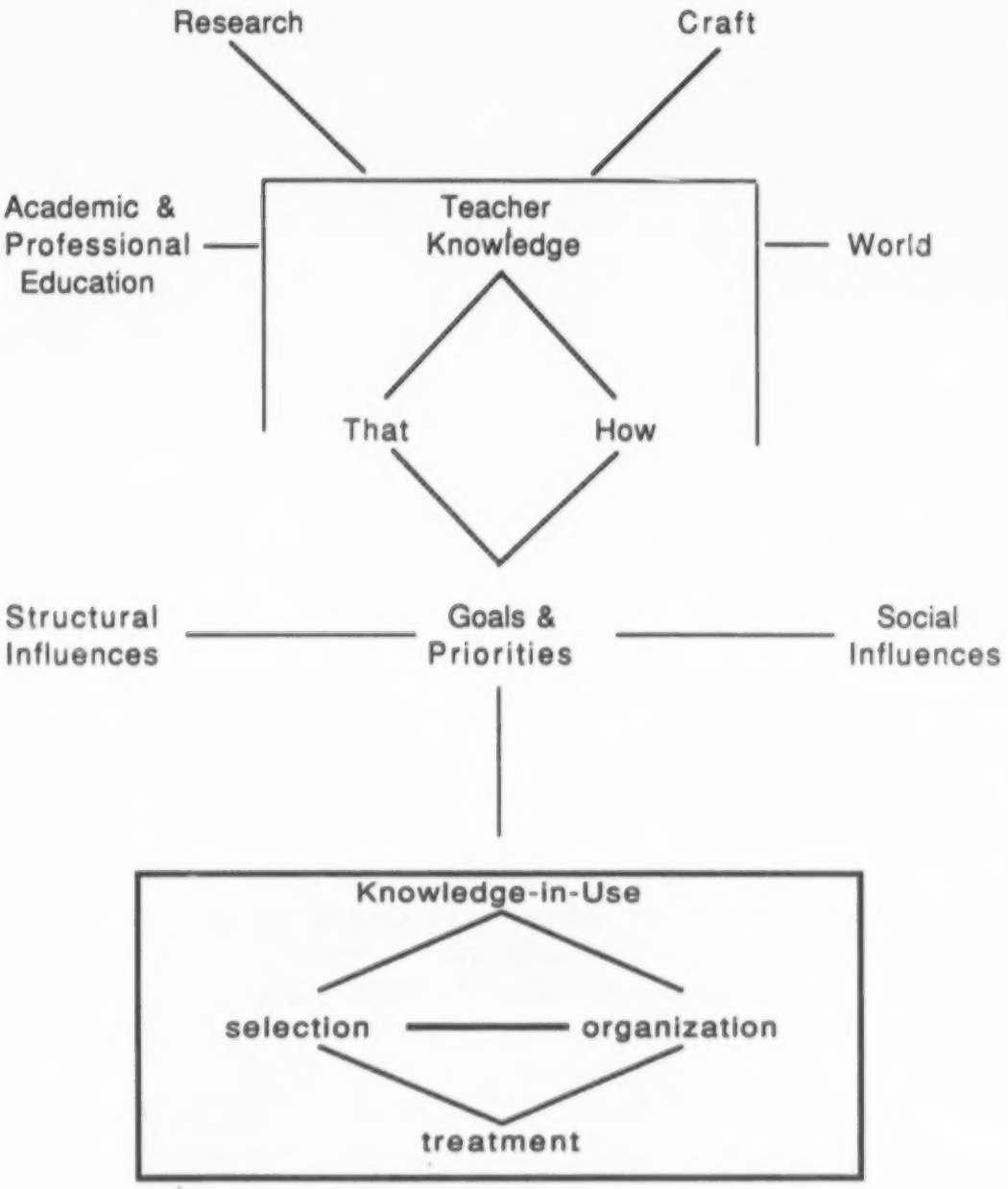

Figure 1. Knowledge-in-use in classroom teaching.

Choices have to be made. Time spent on the War of 1812 means little or no time spent on something else.

Organization is necessary if students are to make sense of what they are studying--if they are to comprehend and perhaps to think critically or creatively about history, not merely to acquiesce to rote memorization. Even if memorization is the goal, the evidence is clear that organization facilitates how much and how easily students learn (see Cornbleth, 1985a for a brief review of relevant research). New Deal programs presented as a list are more difficult to remember and make sense of than are the categories of relief, recovery, and reform presented with illustrations of each. Taking knowledge organization seriously would mean, among other things, eliminating the "list of terms" to define from history classrooms. Instead, teachers would help students to interrelate and map or diagram relationships among key terms rather than copy, memorize, and reproduce definitions.

If teachers are to select and organize historical knowledge for teaching wisely, their knowledge of history needs to be differentiated and organized. Further, teachers need to know *about* knowledge selection and organization for teaching and *how to* best select and organize historical knowledge for their students. Here, three of the four aspects of depth of historical knowledge noted by Suzanne Wilson are particularly relevant and worth reiterating: differentiation, elaboration, and relatedness. *Differentiation* refers to the ability to distinguish components, dimensions, or features of an idea, event, or process and the ability to distinguish major from minor or supporting aspects--what science educators have referred to recently as distinguishing facts from factlets. Differentiation is key to wise selection of historical knowledge for teaching.

Elaboration refers to richness, detail, or depth of knowledge and understanding--beneath the surface or beyond a superficial account. Elaboration is necessary to appreciating complexity and minimizing misconception or misunderstanding--appearances can be deceiving and misleading (as Wilson has illustrated with the Jamestown example). Elaboration is related to differentiation insofar as all details are not equally important or relevant in a particular case, and all the details that a knowledgeable history teacher knows cannot be incorporated meaningfully in teaching 11th graders. Elaboration is important to wise selection *and* organization of historical knowledge for teaching. Appropriate and sufficient cases or details need to be selected in order for students to understand main ideas or concepts--or for students to test hypotheses or generalizations. Cases or details then need to be organized in such a way that their links or relationships to the main ideas, concepts, hypotheses, or generalizations are clear to students. Elaboration also plays a role in the treatment of knowledge as will be shown later.

The third aspect of deep historical knowledge, *relatedness*, refers to integration or organization of knowledge. Historical knowledge can be organized in several ways and at several levels. In addition to the causal and thematic relationships noted by Wilson, we

could note chronological, part-whole, functional, dependency, and contiguity relationships as well as others. Relatedness clearly is essential to wise organization of historical knowledge for teaching. If teachers' knowledge consists of unrelated bits and pieces of history, it is unlikely that they will organize historical knowledge for teaching in ways that are meaningful to students.

Finally, with respect to knowledge selection and organization, teachers need to know what they don't know and where they can obtain assistance. Teachers need to recognize, for example, that they don't know enough about Native-American perspectives on the westward movement of U.S. settlers in the 19th century to select and organize knowledge adequately for teaching about that period of time and those events. But, recognizing the importance of knowledge selection and organization, they also need to know how to find out what they need to know and to be willing to invest the time and effort to learn it.

If I have differentiated, elaborated, and interrelated knowledge about some periods, events, or trends in U.S. history but not others, say the Progressive Era, and I am convinced that wise selection and organization of historical knowledge is crucial to successful history teaching, then I will have some general questions about the Progressive Era that I will try to answer before trying to teach about it. For example: What were the main features of the Progressive Era? What made it Progressive? Why did it occur at this time rather than earlier or later? What were its consequences? For whom? If, on the other hand, my knowledge of U.S. history is neither differentiated nor elaborated nor interrelated, I am less likely to see any need for knowledge selection and organization for teaching or for raising questions such as these when I know little or nothing about a topic.

Knowledge Treatment

Two aspects of knowledge treatment were distinguished earlier, nature of knowledge and its representation or transformation so as to make it understandable to others. Wilson's fourth aspect of depth of historical knowledge, qualification, is relevant to the nature of historical knowledge. All human knowledge is socially constructed. Historical knowledge is particularly contextualized and underdetermined. Based in part on available demonstrated facts, history is a descriptive-interpretive narrative. Either because there is too much or too little demonstrated fact available, historical accounts are necessarily selective and/or partial.

Understanding the qualified (e.g., tentative, created) nature of historical knowledge involves some knowledge of historiography, of modes of historical inquiry--in other words, of how historians do history or how history comes to be. What, for example, are the rules of evidence or grounds for belief? Also, what are the various schools of historical thought? And, what difference do they make? One's selection and organization of knowledge for teaching history ought to be treated as tentative, subject to change given new evidence or compelling alternative interpretation. At times, it should include more than one perspective

or account such as British views of the American Revolution, slaves' views of slavery, and third world nations' views of U.S. foreign policy. Alternative accounts need to be actively sought out through reading and other sources.

The representation or transformation aspect of knowledge treatment deserves much more attention than it has received in teacher education, teaching, or teacher assessment. Since knowledge and understanding cannot be conveyed to students like the passing of the baton in a relay race, teachers must represent or transform their knowledge of history--their selection and organization of historical knowledge--so that it is comprehensible and meaningful to students. To do so, they need an open-ended repertoire of descriptions, explanations, examples, analogies, and so forth. This repertoire is what has been called subject-specific pedagogical knowledge or pedagogical content knowledge (Shulman, 1986). I prefer to characterize it as *content bridges*, bridging teacher and student knowledge. To recognize or create appropriate content bridges, teachers need to know about students' prior knowledge and experiences and their likely misconceptions. Using an analogy to explain a historical concept such as states' rights or Manifest Destiny will not be very helpful when students are unfamiliar with the analogous case.

A major obstacle to enhancing teachers' repertoires of content bridges is that we do not yet have much codified knowledge of appropriate knowledge representations or transformations for teaching history. We have multiple models of the selection and organization of historical knowledge but not of its treatment in ways that maintain its integrity and make it accessible to students. This is an area of needed knowledge, a potentially productive area of field research that would capture and make available the tacit knowledge of expert history teachers.

Concluding Comments

All right, you might say, but if you want teachers to know about knowledge selection, organization, and treatment and about knowledge-in-use, how are you going to fit that into preservice or inservice teacher education--or, what are you willing to give up? There are trade-offs. Personally, I would trade breadth of historical knowledge for depth. I would prefer teachers who know more about less to teachers who know a little about many things. Of course, I also would want teachers to know what they don't know, what kinds of questions to ask, and how to obtain answers.

All right, you might say again, but what history do you want teachers to know in depth? That depends, I suggest, not entirely evading your question, on your conception of history and your reasons for teaching history in the schools. With respect to the latter, for example, do you see U.S. history being taught for its own sake, to prepare junior historians, to promote patriotism, to contribute to democratic citizenship, or for some other reason?

One's goals and priorities suggest different selections for in-depth study by both teachers and students.

Personally, I give priority to U.S. history for democratic citizenship, which I see as informed and active. I would emphasize knowledge of U.S. history that offers perspective on the present and common ground if not a common heritage. It would show democracy as a continuing quest, the U.S. experience being one of expansion of political democracy and continuing, sometimes bitter struggles for economic and social democracy in an often difficult world. Themes, concepts and trends, and events in social and political history would be emphasized, incorporating relevant social science concepts, probably at the expense of formal diplomatic and military history. For example, I would emphasize the experience and effects of the U.S. Revolutionary and Civil Wars rather than the battles and generals. In response to the questions of whose history is to be taught, I prefer a peoples' history to an elite version. In either case, teachers need to have knowledge of multiple perspectives and to share them with students. Finally, given the state of the world, whatever U.S. history is selected or emphasized should not be known in isolation from the rest of the world; the U.S. experience ought to be understood in its global context, past and present (cf., College Entrance Examination Board, 1986).

In making decisions about what history is particularly important for teachers to know in depth, it is helpful to know something of the history and epistemology of history and of history as an academic discipline and a school subject. Such knowledge facilitates recognition of underlying assumptions and implications of our choices. Ideally, I would like teachers to have this knowledge also, to inform their selection, organization, and treatment of knowledge for teaching history.

To sum up, then, the knowledge needed for teaching history well is not only (a) differentiated, elaborated, interrelated, and qualified historical knowledge, but also (b) knowledge *that* the selection, organization, and treatment of knowledge is crucial to successful history teaching, (c) knowledge *how to* select, organize, and treat knowledge for teaching history, and (d) knowledge of factors that affect knowledge-in-use in history teaching.

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MUSTS FOR WRITING TEACHERS--REPORT FROM THE CLASSROOM

Tom Romano[19]

Do not think the youth has no force,
because he cannot speak to you and me. Hark!
in the next room his voice is sufficiently
clear and emphatic.
Ralph Waldo Emerson (1934, p. 91)

The room where I spend much of my time is the room where I write. Books. Desk. Chairs. File cabinets. Computer. I'm at home in this room. Before I began writing this paper, however, I went to another room that is important to me--"the next room," the place where I have taught English to teenagers for 17 years, the place where they have read and written and talked. My classroom. I wanted to learn what my students thought writing teachers must know. In matters of education the voice of youth is usually ignored and rarely sought. I didn't want to perpetuate such error.

And it is error. To teach without listening to students is foolhardy. We learn how to teach better, with more accuracy, insight, and relevance if we listen to those who learn with us, whether they be first graders or graduate students. I asked my 10th and 12th graders to write about this question: What things must a writing teacher know in order to teach writing well and help teenagers become better writers? Their responses form the core of this paper.

"Teachers," writes Aimee, "should be experienced writers so they can understand what their students have to go through to write an interesting paper. They wouldn't have to be genius college professors to teach good writing. They just need to be loyal writers." Not necessarily even published writers. Just loyal ones who do enough writing about personally and professionally important topics to see writing from the inside, to know which strategies for teaching writing ring true and which clang.

Literature and Writing Courses

English teachers traditionally get most of their training in literature classes. They are studiers of literary artifacts. Rarely are they makers of literary artifacts. Instead of writing literature, they write *about* literature: Renaissance literature, Victorian literature, romantic American literature. While enriching and essential to making prospective English teachers well-read, such study does not make them excellent teachers of writing.

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It makes them amateur critics equipped to evaluate the literary artifacts of professionals. Different reading skills and sensitivity, however, are demanded of those who would read the unfinished writing of secondary school students, who would nurture their growth as writers, as thinkers. Teachers need to know, as Kristine says, "how to help students on difficult spots." Timely instruction or reassurance may be all a student needs on her way to developing a draft.

"A writing teacher," notes Bryan, "must be able to feel what the student is trying to say; that teacher must be able to connect with the words on the page. He or she must be able to identify what works and what doesn't work in a story. It is important for a teacher to be able to sense if a small composition might be a doorway to a gigantic story that lies hidden." Teachers must know how to read evolving writing, writing that isn't there yet, but could be. This is a different skill than merely knowing how to criticize. Reading student writing means being sensitive to the nascent, the embryonic, the possible.

Prospective teachers need plenty of experience in writing courses, those in which instructors respect individual voices and help each writer gain sophistication and versatility in the use of written language. If students--near-teachers--leave college seeing themselves only as critical readers, and not also as writers, many of them will fall easily into an elitist view of written language, one that pigeonholes the writing of students as second rate.

"English teachers should have experience with lots of different styles of writing," acknowledges Rosanna, "and they shouldn't be prejudiced about a student's writing." Our schools house students of great diversity. The range of education, culture, and intellect is incredible. There are students whose reading is so vast, whose home life so literate, whose facility with language so accomplished, and whose motivation so high that they already possess literary voices. And there are students whose reading is so meager, whose home life so aliterate, and whose motivation so low from repeated educational defeats that their written voices are, at best, halting, at worst, mute.

But both voices and all those between them have places in our democracy, are entitled to speak, "each," as Walt Whitman (1981/1855) put it, "singing what belongs to him or her and to none else" (p. 14). And those varied voices, the literary as well as the nonliterary, can develop in skill under the guidance of teachers who accept them without prejudice and who know writing from the inside. To know writing from the inside, a writing teacher must write. So imperative is it that they be loyal writers, as Aimee said, that I would call this brand of educator a *teacher-writer*, the two nouns bonded by a hyphen. Teachers who write, writers who teach. Teacher-writers put pen to paper frequently, and for more reasons than writing comments on student papers and jotting bathroom passes.

Teacher-writers know the transformative power of writing. They know that writing, as Donald Murray (1985) has written, "is a satisfying human activity that extends both the brain and the soul. It stimulates the intellect, deepens the experience of living, and is good

therapy" (p. 73). Teacher-writers try their hands at various modes of writing, become learners in many genres: essays, letters, poetry, fiction. Through such experience, teachers learn the "territory" of writing both "intellectually and emotionally" (p. 74). Teacher-writers, as Stephanie understands, "know the *pains* of writing. Beginnings, endings, writer's block, a thousand rough drafts."

Teacher-writers speak from knowledge born of doing. "The teacher needs to be able to write and create so he can show the tools of the trade," writes Eric. Teacher-writers can show these tools of the trade because they use them. They know what it's like to draft five leads in order to find one that's suitable. They know first hand the faith it takes to head into a topic and trust the generative powers of mind, imagination, and language to produce writing.

Power of Classroom Community

Teacher-writers also must understand the sustaining power of a classroom community. Although a good deal of writing is done alone--the writer left to the solitary harmony of eye, mind, and hand--teacher-writers recognize the immense value of the social aspect of learning to write. In *Language Stories and Literacy Lessons* (Harste, Burke, and Woodward, 1984) Jerome Harste notes,

> Discussion with neighbors prior to, during, and after involvement [in writing] are not disruptions to the process, but a natural part of the process itself. Successful writers use friends in order to discuss where they might go next and what arguments still need to be developed, and to verify for themselves that their writing has the effect they desire. Opportunity to build from the natural support of the classroom should be part of the language arts. (p. 214)

Teacher-writers know that students need not be lone wolves, uncommunicative, talking with no one about their writing. "An English class always comes across as just writing and reading," Karen explains, "but I think it should be writing, reading, and more discussion (Here's a word I learned in English: confer). Students should be able to confer." Writing is a social act; writers seek to reach others.

Developing a sense of audience is crucial to learning to write. Stories, poems, plays, and essays are not created perfunctorily. They are aimed at flesh-and-blood readers. In the writing class, students read the evolving writing of their peers. They reveal what they've understood, ask genuine questions, and may offer suggestions. When writers are involved in making meanings, in plumbing the depths of their thought and language, conferring with others helps them to see with different eyes.

Gaining the response of others and learning to gage the needs of audience are reasons enough for students to share writing with peers, but there is another: "Sharing writing," Jeff

argues, "gives students the satisfaction that this piece was not written for just another grade." When students have worked hard creating with language, that work deserves a time of group acknowledgement. Writing must not merely be handed to the teacher for marking and handed back to students for filing. Student writing needs to be celebrated.

Teacher-Writers as Respondents

Key models of sensitive responders and appreciative celebrants are teacher-writers. By their intent listening, their genuine interest, their desire to help without bullying, teacher-writers demonstrate to every member of the writing class the respect which all writers need in order to risk learning and to grow. "A teacher has to remember when he was a teenager and what he was thinking," writes Carrie. "Nine out of ten [teenagers] are thinking about what they're going to do for the weekend or how much their paycheck will be for the week."

If teacher-writers expect to communicate with teenagers, they must remember their own teenage mind. They have to remember adolescence with compassion, have to feel anew the sting of self-consciousness, the ache of being jilted, the desperate need to be accepted. When teenagers are asked to write their truths, as they must again and again, matters of personal significance arise. Students may be writing about the role of women in Hawthorne's *The Scarlet Letter.* They may be writing about the death of their beloved grandfather. In either case, the topics should be inextricably bound to the writer. Effective writing rarely comes without deep involvement.

And although writing can be improved and rhetorical strategies can be taught, students first need to be safe, need to know that their teacher respects the personal level of the writing. The writer and the writing cannot be divorced. "Writing is the writer. It embodies her voice, her passion, her thinking, her intellect, her labor, and, on some occasions, her very soul" (Romano, 1987, p. 125). Teacher-writers must be sensitive, but not to language alone. They must be sensitive to people. Teacher to student. Person to person. Writer to writer.

Sensitivity to Risk

This respect and sensitivity extends also to the realm of risk and error, two concepts whose relationship either enhances learning or sabotages it. Teacher-writers understand that risk and error are companions of learning. To become more accomplished writers, students need to risk trips into new territory, need to try the untried.

Although students work to perfect many skills and become proficient in routine matters of writing, they also need to attempt the new--new genres, new strategies, new words. And teacher-writers must understand that risk--and the errors that attend risk--are to be applauded. When students take risks, that means they are in the midst of learning. And teacher-writers must know that when students risk trying new skills, they may temporarily regress in old skills that seemingly had been mastered.

Holly, for example, is a bright sophomore I taught last semester. She saw topics for writing all around her. She wrote fluently and took pleasure creating her vision in essays, narratives, and poems. About 12 weeks into the semester she boldly entered new territory, began writing fiction, a genre she hadn't tried before. Her short story ran 12 pages, about 3000 words, three times longer than anything she'd written before--a breakthrough for her.

The final draft of her short story, however, was plagued by comma splice errors. On previous pieces Holly had appeared to have that particular punctuation malady under reasonable control; but on this piece, this brand new, all-consuming attempt, Holly's attention to the editing skill of marking off sentence boundaries had lapsed.

I was disturbed by the comma splices and knew I'd have to reteach her the concept of sentence sense, but I knew something else too: I knew that the comma splice relapse was minor compared to the great strides Holly had made as a writer. She had managed so many new, complex skills in this notable first effort in fiction. She had developed believable characters, had carried forth a narrative with a fine interplay of description and dialogue; she had created a plausible plot and worked out a satisfactory resolution. These are no mean feats for a high school sophomore. Comma splices or no, this 15-year-old was on her way to becoming a capable, independent adult writer.

Teenagers More Than Proofreaders

Teacher-writers know that surface manuscript errors--those of spelling, punctuation, and usage--must be kept in perspective. It is easy to become fanatical about eradicating surface errors. They are oh-so-obvious. But when teachers lose perspective on this matter, they elevate copyediting to the ultimate concern. And this unwarranted elevation relegates other matters of composition--crucial ones--to inferior positions. Teacher-writers cannot let that happen because . . .

- developing the confidence to write fat first drafts is more important than spelling . . .
- learning to focus writing is more important than good margins . . .
- becoming proficient at revising writing for clarity and vividness and a rhythmical, readable style is more important than avoiding comma splices.

Teacher-writers must understand that they are teaching teenagers to be more than proofreaders. They are teaching them to be writers, critical thinkers who take responsibility for the totality of their work. Writers make language and meaning choices, then they evaluate them. And based on that evaluation they make their next move. Certainly teachers must work patiently with students to teach them the copyediting skills needed to prepare manuscripts. But that is only part of a teacher-writer's role. We have all read enough insurance forms and administrative reports to know that perfectly edited manuscripts alone do not ensure good writing.

Nor does a flawless mastery of grammar. Should teacher-writers know grammar, the how of language? Of course they should, to a degree. But they don't need to know grammar as deeply as linguists or editors. They *do* need to know, however, that teaching formal grammar does not improve students' writing. In his book *Research on Written Composition: New Directions for Teaching,* George Hillocks (1986) examined 20 years of writing research. On the longtime tradition of teaching grammar, Hillocks writes,

> None of the studies reviewed for the present report provides any support for teaching grammar as a means of improving composition skills. If schools insist upon teaching the identification of parts of speech, the parsing or diagramming of sentences, or other concepts of traditional school grammar (as many still do), they cannot defend it as a means of improving the quality of writing. (p. 138)

Teacher-writers need to know punctuation, grammar, and usage in order to show students how to make purposeful use of them within the context of their writing: how a colon or a dash, for example, can abruptly halt a sentence and signal importance to the detail that follows; how a fragmentary sentence can emphasize an idea; or how diction affects tone. Was the *spy terminated*? Or was the *foreign visitor murdered?*

Teacher-writers know that the process of learning to employ the rules of written language and to utilize their flexibility are affected by culture and experience. It is a lifelong process that most of us will never master completely. And it is a process best undertaken with curiosity and a sense of humor. I observed a high school junior, on one occasion, write about the extinction, millions of years ago, of that marvel of reptilian evolution--the poor, doomed "Dinah Shore." And I have seen the marks of my copyeditor pointing out to me the difference between *complement* and *compliment*. Curiosity and sense of humor. My teaching is complemented by them. And so is my learning.

Writing Lives in the Big World

Teacher-writers must understand that writing lives in the big world. Writing is not a snapshot; it is a mural. The literate world we want students to inhabit contains many kinds of writing, everything from folktale to rap. Within its borders are light verse and letters and literary analysis. But many secondary school English curricula do not reveal writing as a big world mural, so heavily do they emphasize literary analysis to the virtual exclusion of every other genre.

Literary analysis is surely one valuable kind of writing, but not the only kind, and certainly not of such eminence that English curricula should make it the sole focus of interest. If teacher-writers want students to value writing, to readily use it for personal expression, then students must get chances to write far more than literary analyses. Students

must see themselves as potential creators of all kinds of writing, not just the kind that is about someone else's writing. I want students to write poems, fiction, persuasive essays, drama, memos, reviews, letters of love, complaint, and praise. I want to enfranchise students as creators of literary artifacts.

Teacher-writers can start granting validity to all forms of writing by making no condescending distinction between expository writing and so-called "creative writing," as if the latter were some airy-headed, nebulous genre that involves no rigor in diction, syntax, logic, selection, analysis, and synthesis. If anything, teacher-writers must show students how creativity--the merging of intellect and imagination--infuses all genres in the big world mural of writing.

Teacher-writers must know that writing--like woodworking, swimming, and gardening--improves with plenty of real practice. Composing occasional isolated paragraphs or even more substantial pieces only once every six weeks' grading period will not provide enough practice to improve skills, strengthen voices, and make easy and familiar the immersion into written composition. Teacher-writers know that class time is invaluable and, therefore, no use of it surpasses that of students bent to paper, writing their meanings in individual voices, especially in a democracy that thrives on freedom of expression.

Connection Between Reading and Writing

The literacy coin has two sides. Writing is one side. Reading is the other. Teacher-writers know that without reading there is little reason to write, and without writing there is no reason to read. "What makes a story, poem, or book good is its ability to interest the reader," writes Mike. "In teaching teenagers who don't really know exactly how to trap a reader's interest, a teacher should encourage a young writer to read different assortments of writing."

Teacher-writers must be wide readers.

Although it is important that teacher-writers know traditional literature, they must also be readers of contemporary literature. Contemporary literature offers a virtual seminar in effective writing techniques. Teacher-writers can bring them into the classroom to teach students rhetorical strategies, like using a very short sentence to end a passage pointedly or employing the "power of threes" to create strong, memorable repetition--three parallel sentences, three rhythmical phrases, three revealing words. The voices of contemporary literature are those of our time. Like students, those voices are gloriously diverse. And they are the voices I want my students to learn from.

There is another kind of contemporary literature teacher-writers must know, one that connects directly with teenagers. It is the literature written for young adults, typically referred to as YA literature or adolescent literature. The best writers are voracious

readers. And teacher-writers want students to read. It is through wide reading that students can learn a love for language, a sense of story and persuasion, a feel for the written word.

This young adult literature is not second rate, by any means; it is high quality. In her comprehensive and powerful book about teaching literacy to adolescents, *In the Middle*, Nancie Atwell (1987) argues,

> The last 20 years have witnessed an explosion in the number of novels and short stories written expressly for young adults, adolescent literature of such breadth and depth no teacher need ever apologize for building a curriculum around kids' responses to their own books. Much of the writing--I'm thinking of Robert Cormier [1974, 1988], Lois Lowry [1977, 1978], Susan Beth Pfeffer [1980, 1987], Madeleine L'Engle [1962], Robert Lipsyte [1967]--is exquisite. (p. 161)

The key to this young adult literature is the direct appeal of its characters and subject matter to adolescents. In it they can find characters at or near their own age confronting the problems of the world. Young adult literature is the surest bet to get students hooked on reading. The more young adult literature teacher-writers know, the better their chances of luring students to literacy.

Professional Development

The teaching of writing is an exciting profession. Researchers are going into real classrooms and examining how students best learn to write. University researchers like Donald Graves (1983, 1984), Jane Hansen (1987), and Glenda Bissex (1980), and excellent classroom teachers like Susan Stires (1988, 1989), Carol Avery (1987, 1989), and Linda Rief (1985, in press) have conducted research and published their findings in books and articles. Such reading is not only informative and stimulating, but also vitally necessary to ongoing professional development.

Teacher-writers need to know that continued growth in their field will help keep them vibrant in the classroom. In addition to doing professional reading, teacher-writers may also grow professionally by attending national, regional, state, and local conferences sponsored by the National Council of Teachers of English, the Modern Language Association, and many universities and colleges. At such conferences participants can be introduced to new skills and approaches to teaching writing and can be inspired by the best thinkers in the profession. And teacher-writers working critically and creatively may more actively join this sharing of ideas by proposing their own presentations for these conferences. All this professional activity serves to reinvigorate teacher-writers and to reaffirm their commitment as members of a community dedicated to quality literacy instruction.

Environment Often Antithetical to Good Learning

They will need such reinvigorating. Often the environment for teaching writing is antithetical to what we know would make for good learning. Many secondary teachers struggle to teach writing under the burden of six classes per day with as many as 25 and 35 students in each class. And administrators rarely look upon teachers as reflective professionals who need reasonable workloads and time built into the school day for intellectual interaction with colleagues to discuss research, debate issues, and collaboratively explore problems and propose solutions. More often, teachers are viewed as hired hands who don't really need to think, who need only keep the corral locked and the beasts within orderly and able to jump through standardized testing hoops that do not measure actual ability to initiate written text.

Although this issue is crucial and realistic, a part of the present territory that teacher-writers will enter, I don't want to conclude with that point. It leaves the written word, and I want to end by returning to it. The one thing I would have every teacher-writer know--not tacitly, but overtly, not theoretically, but experientially--is this: the act of writing is an act of thinking. Here's how Peter Elbow (1983) described this relationship between language and thought:

> Once you get yourself writing in an exploratory but uncensored fashion, the ongoing string of language and syntax itself becomes a lively and surprising force for generation. Words call up words, ideas call up more ideas. A momentum of language and thinking develops and one learns to nurture it by keeping the pen moving (p. 39).

Obvious? For years it wasn't obvious to me. And I've loved writing since I was 12. I have taken pleasure in the quiet thrill of a story, a line of argument, or a personal realization forming under my pen. I have taken pleasure in thinking. And the best language, the best ideas often occurred unexpectedly as I was actually putting words on paper. Teacher-writers must put this concept of "writing as thinking" to work for themselves by writing. And they must trust in it passionately enough to allow the concept to go to work for their students.

"Let students write," says Troy. "A writing teacher's main goal should be to open up the channels in each of his students to let them put their ideas and emotions and personality on paper." Krissy provides a different slant to this. "The most important thing that a teacher should tell his students," she writes, "is to not be afraid. He should stress to the students that if you think you have something then go with it."

Like Krissy, I believe it comes down to courage. But I would try to persuade her that teacher-writers must not just *tell* students to be courageous. Teacher-writers must *be* courageous. It takes courage to enter a profession that is perpetually underfunded,

undervalued, and often undermined. It takes courage to work with other human beings and believe that your skills will help them become better writers. And whether teachers are in their classrooms or at their writing desks, it takes courage to remain open to all possibilities and yet maintain enough faith in themselves to understand clearly, without doubt, when they really have something. And it takes courage to go one step farther, to *act* upon that understanding, or as Krissy recommends, "to go with it."

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THE KNOWLEDGE NECESSARY TO TEACH WRITING EFFECTIVELY[20]

George Hillocks, Jr.[21]

Teachers of writing ought to be writers, just as teachers of piano ought to be pianists. Teachers of piano need not be great concert pianists, but we expect them to play, with more than mediocre facility, at least some works of Bach, Brahms, Chopin, Liszt, Mozart, Beethoven, and Debussy. So, we should also expect the teacher of writing to write on a variety of topics and in a variety of genres (personal essays, stories, arguments, analyses, poems) if for no other reason than to know what it is like to write them. At the same time, we expect the skilled piano teacher to have a body of knowledge about music theory, the techniques of piano playing, and piano music--knowledge which can be brought to bear in teaching. Similarly, the teacher of writing requires a body of knowledge about writing and the teaching of writing. What that body of knowledge encompasses, however, is not so clear.

In order to examine the knowledge necessary to teach writing effectively, we need to address two enormously complex questions: (a) What does *writing* encompass? and (b) What is involved in the effective teaching of writing? Although we do not have the knowledge to provide definitive answers recent research and theory provide frameworks for addressing both.

The Territory of Writing

Research and theory over the last 20 years or so have expanded the territory of writing to include not only the nature and quality of written products but processes involved in bringing them into existence. A number of researchers have concentrated on what might be called the general writing process. Others have examined specific subprocesses used in generating form and content. Instructional studies have provided insight into the differential effects of focusing on various kinds of knowledge in the teaching of writing. Taken together, these studies indicate that, for effective teaching, the territory of writing includes knowledge of the general writing process, knowledge of processes for producing particular kinds of discourse, and knowledge related to developing content.

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General Writing Process

A number of researchers and theorists have argued for the primary importance of what I will call the general writing process (e.g., Calkins, 1983; and Graves, 1983). These researchers and theorists emphasize the need for generating ideas before writing (prewriting), drafting, receiving feedback from real audiences of peers, revising, editing, and finally publishing the writing by sharing it with audiences in a variety of ways. Anyone who writes knows the importance of these general processes for writing. However, many youngsters do not know this.

Every fall for the last eight years, a small group of prospective English teachers and I have taught a group of seventh graders in the Chicago public schools. Every year during the first writing these students do for us, five or six bottles of "whiteout" appear. The youngsters bend closely over their work, meticulously using the whiteout to eradicate errors, improve handwriting, correct spelling, and even space words more adequately. This year, one girl used whiteout seven times in a single line. Clearly, these students have much to learn about the writing process. They need to know that writers produce preliminary lists and drafts, scrap entire passages, cross out words, insert material using arrows or asterisks, and revise several times before achieving what they desire.

At the same time, learning to engage in the general writing process does not entail learning the particular strategies necessary for effective writing. For example, *Time's* cover story for February 6, 1989 (Church, 1989), on the use of weapons by citizens, points out the difficulty of "writing a definition of paramilitary weapons that would distinguish them from some types of semiautomatic hunting rifles," precisely the kind of definition necessary for effective legislation prohibiting the sale of such weapons. If the writer of such a definition does not know what criteria are, how to generate them, and how to use examples to illustrate them, no amount of prewriting, drafting, revising, and editing will help produce an effective definition that can pass the muster of legislative action.

Process and Specific Writing Tasks

It seems almost intuitively obvious that the processes required in drafting a narrative about personal experience will differ markedly from those involved in writing an extended definition for a piece of legislation or an argument to convince someone to vote for that legislation. Carl Bereiter (1980) suggests a model, which I have adapted in Figure 1, for examining the subprocesses involved in specific writing tasks. This figure represents levels of decision making in the composing process.

Purposes and Constraints

At the top of this inverted triangle are the purposes and constraints which control the production of a piece of writing. The purposes in writing are ordinarily both affective and substantive; that is, a writer wishes usually to make a point about some subject and to elicit some response from an audience. In technical writing, for example, the writer may wish the

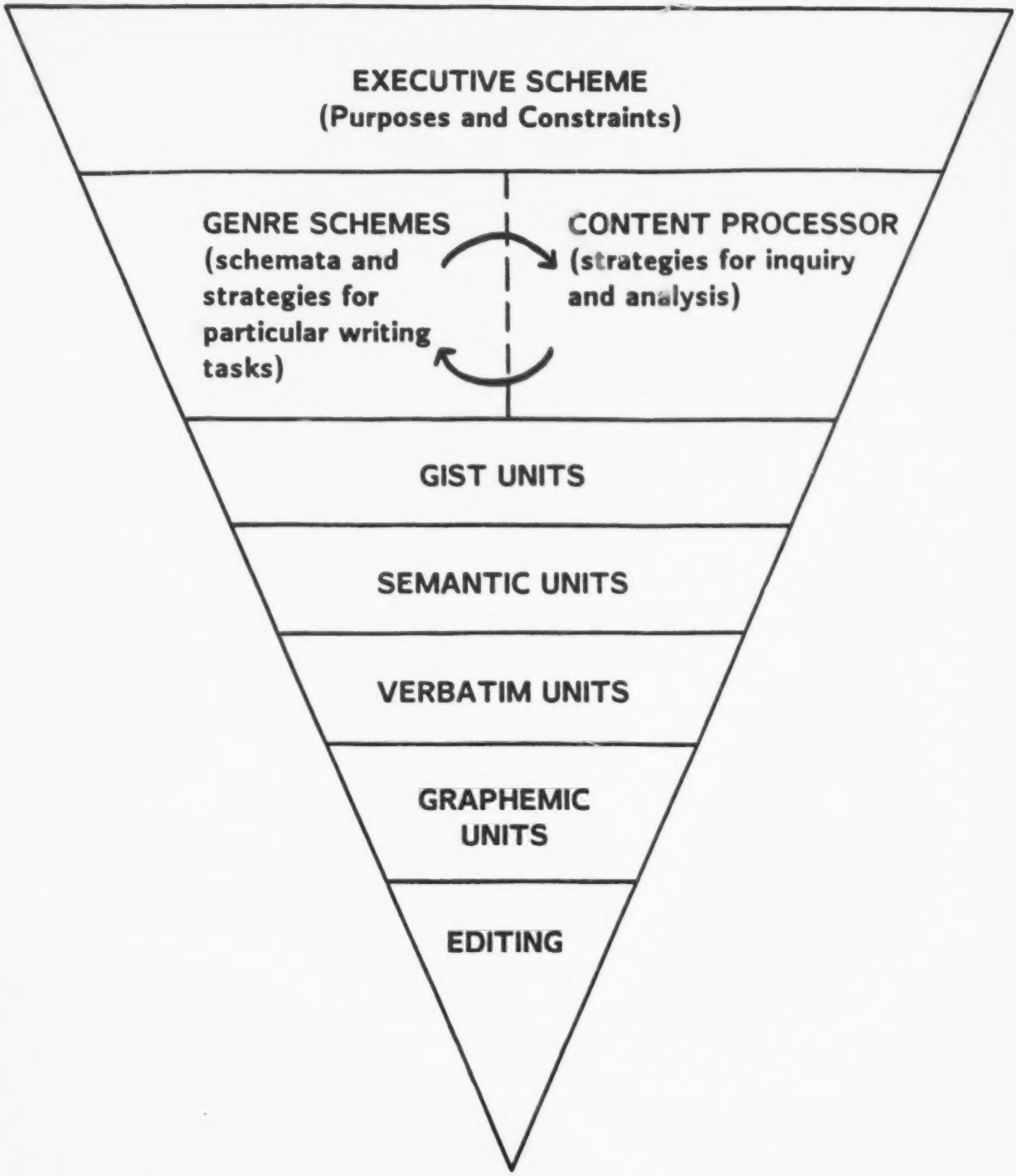

Figure 1. Decision-making levels in the composing process.

audience to examine each piece of data in a detached fashion, assessing its value along with the conclusions reached by the writer. In a narrative about personal experience, in contrast, writer may wish to evoke empathy from the audience.

Some kinds of writing may not be purposive in this sense at all. Statements by such writers as Blake, Conrad, Tolstoy, and T. S. Eliot suggest that sometimes the writer produces almost compulsively without a conscious notion of purpose. A. E. Housman (1938), for example, writes of downing a pint of beer at luncheon, resuming his walk on Hampstead Heath, and having two stanzas of a poem "bubble up" from "the pit of the stomach." The third stanza came "with a little coaxing after tea." Of the fourth stanza, he says, "I had to turn to and compose it myself, and that was a laborious business. I wrote it thirteen times, and it was more than a twelvemonth before I got it right" (pp. 49-50).

The first three stanzas produced by Housman seem to have been composed without concern for an audience's response. For such material, the usual criteria for judging writing (which derive from the audience/writing relationship) are irrelevant. Housman's concern for getting the fourth stanza "right" suggests that, by that point, he did have a purpose and, therefore, criteria in mind. It may be that writing sometimes begins without a conscious purpose but takes one on as the writer becomes aware of subconscious goals.

The constraints under which writers work will include the time available, their perceptions of their own involvement in the communication situation, and most important, the audience. Audiences that writers encounter in the real world vary along certain key continua: close and intimate to distant and unknown; uninformed to highly knowledgeable; accepting to skeptical. Sometimes, in an effort to develop their students' confidence as writers, teachers try to restrict the audience dimensions of a classroom to the known, accepting, and friendly. But writers in the real world need strategies for dealing with skeptical audiences as well.

Genre Schemata and Discourse Knowledge

The purposes and constraints under which a writer works influence decisions about what Bereiter (1980) calls "genre schemata." A schema may be defined as a patterned set of categories used to organize and interpret incoming information and to guide subsequent verbal and nonverbal behavior. An example of "genre schemata" which has been carefully researched by psychologists is that of the story schema (Stein and Glenn, 1979; Stein and Trabasso, 1982). Work on the analysis of schemata which control conceptions of argument has also begun (McCann, 1989; Stein and Miller, 1988). Although we have much to learn about "genre schemata," writers appear to elect some schema (or invent one) early in the composing process--one that is suitable to the writer's purposes. Accordingly, a writer's knowledge or conception of the schema will guide the production of a particular piece. If

a writer's schema for argument is limited, so will be the particular arguments that writer produces.

"Genre schemata" may be the most important part of a writer's knowledge of discourse, for they come into play early in composing and guide everything that follows. Syntactic knowledge, another part of discourse knowledge, does not come into play until after the level of gist units, chunks of discourse envisioned but without the benefit of specific words and sentences. The discourse knowledge having to do with the conventions of mechanics, spelling, and usage appear not to come into play until the production of graphemic units and editing (see Figure 1). Ironically, the discourse knowledge receiving most attention in schools (certain limited conceptions of grammar and conventions of usage and mechanics) have the least impact on the final form of written compositions. It would seem that enhancing discourse knowledge at the level of "genre schemata" would do much more to improve writing.

One objection to teaching knowledge about discourse at the level of "genre schemata" is that it leads to formulaic writing. At one level, writers probably use relatively formulaic patterns to help them generate pieces of discourse, e.g., some business letters, some memos, letters of recommendation (Anderson 1985), and the five paragraph theme that Emig (1971) found her students using. At another level, however, discourse knowledge appears to operate in the composing process in a way that is not at all formulaic.

An example appeared in a study my students and I conducted a few years ago. We asked the youngsters attending a summer writing workshop at The University of Chicago to do the following: "Write about an experience, real or imaginary, that is important to you for some reason. Write about it so specifically that someone else reading what you have written will see what you saw and feel what you felt." Of the 40 students writing in a large classroom, my graduate students and I observed a stratified random sample of 19 during the writing. As each of the youngsters concluded his or her writing, one of the graduate students took the writer to another room to talk about what had just been written. The first questions in the interview asked the writers what they considered writing about before they actually began writing. Eighteen of the 19 students observed considered content of some kind first. That is, they thought of a summer vacation, a trip to an amusement park, a school related adventure, or some other specific experience.

One 14-year-old boy, however, said that he did not know what he was going to write when he began. He did, however, know the kind of story he wished to write--one that would be mysterious and puzzling and that would have a surprise ending, "a twist," he called it. The story begins with the line, "Where's the floor?" He chose that line, he says, because he thought it would get people's attention. He claims he did not know what would come next, that for him writing the story enabled him to discover what would happen next.

The story develops in the first-person narrative as a nightmarish dream sequence and ends with a double ironic twist. The writer in his interview was able to describe the kind of story he wanted to write in his own words and to compare what he had done to certain stories by Edgar Allan Poe. When the story was rated holistically, it received the highest rating from three raters. Here was a complex first-person narrative with ironic twists written in 50 minutes by a young man who claimed that he did not know what the content of the story would be when he began it. Here is a case in which discourse knowledge apparently guided written production but not in a formulaic way.

Anderson (1985) points out that "discussion of forms is unpopular at present because of the movement in composition pedagogy . . . away from an approach that focuses on the characteristics of good writing to one that focuses on the processes by which good writing is created. As a result, discussion of the forms of writing tends to be scorned" (pp. 11-12). Anderson outlines several reasons why attention to "forms" is important: (a) the competent use of conventional forms in a job setting marks one as a "bona fide member of the culture of the workplace" (p. 12); (b) conventional forms help readers know what to expect as they read; (c) knowledge of form probably operates as an integral part of the composing process, as strongly suggested by the example above.

Teachers of writing clearly need a theory of discourse that will enable them to think about the demands of various writing tasks. Unfortunately, which theory of discourse is most appropriate for teachers is not at all clear. Several competing theories are available. Probably the most useful current theories for teachers are those devised by Kinneavy (1971) and Moffett (1968). In addition, teachers will find knowledge about modern developments in the analysis of style and cohesion useful. Colomb and Williams (1985) provide an informative example.

Judging writing. In addition, teachers need to be able to judge specific pieces of writing, diagnose problems in light of writers' purposes, and use that knowledge to guide their instructional planning and coaching. The question of what effective writing is cannot be answered in the abstract. What is effective for a narrative in a short story may not be effective as a narrative for *Time* magazine. An effective argument in a personal letter may not be effective in a court of law. The criteria for judging the effectiveness of writing vary with the purposes of the writer, the attitudes and knowledge of the intended audience, and the context in which the writing is received (e.g., read in private, listened to in public). Teachers need to understand how criteria vary within the range of purposes, audiences, and contexts. Being able to apply these criteria during the course of instruction is crucial to coaching individuals, to evaluating the effectiveness of instruction, and to revising instructional plans to meet the needs of individuals.

The following two pieces of unedited writing illustrate how criteria help guide instruction in general and the coaching of individual students. Both were written at the end

of a sequence of instruction, the goal of which was to enable students to write personal narratives capable of arousing empathy in an audience. The first composition is the posttest for the sequence. The second, the revision, is a follow-up to the posttest. Most readers will recognize some difference between the two pieces. But what precisely is the difference?

The Soccer Game

> Last weekend I was in a soccer game against Hammond. It was almost the end of the game when I scored for our team. Our Coach called me out of the game. He welcomed me to the side with a cheering smile. He yelled, "that's the way to do it" and he asked How I got the goal. I replied, I got a pass from Charlie and I kicked the ball inches from the goalie and then it went in." My coach said, "that I'm improving at the game and that I will be fantastic in the years to come." As I sat down on the soggy grass, my dad came over and he commented on the great score I made. I said, "I just got lucky." My dad asked, "If I needed a ride at the end of the game" and I said, "yes, I need a ride." Then me and my family drove home from the thrilling soccer game.

* * * *

> There was a minute in the thrilling soccer game left. Our team, the vikings were tied with Hammond 1 to 1. I was dribbling the ball at a fast pace down the field. I could hear the other team's feet trembling against the hard, dry ground. The light-weighted soccer ball was gliding over the hard surface every time I gave it a soft tap. My heart starting pumping faster as I closed up on the other goalie. My teammate, Charlie was following me on my right side. My feet felt like two humming birds flying to their nests. The fullback on the other team was pushing my shoulder trying to lure the ball away. I passed the ball to Charlie who was just a few feet ahead of me. He dribbled the ball to the goalies box then he centered it to me. I started shaking like a leaf as I kicked the ball past the darting goalie and into the big goal net. I started jumping for joy as my teammates came around me to share my happiness.

The first composition is far more specific than the young man's earlier writing had been. It includes specifics about the game, the score, how the winning goal was scored, what the coach said afterwards, what the father said, and what the boy said. Encouraging writers to be more specific was one of the goals of instruction.

But there is something missing. The writer provides no sensory details that allow us to capture the specifics of the scene and action in our imaginations. Nor does he supply specifics which reveal his own personal feelings or state of mind during the event. We have to supply those details ourselves. The writer appears not to have considered audience response, but has used what Bereiter and Scardamalia (1982) call a what-next strategy. He adds one detail after another as he recalls the events. Curiously, although the intended

center of the composition is scoring the goal, that particular event and the writer's immediate response to it have largely been ignored.

At the suggestion of the teacher, the writer focuses in on scoring the goal. The teacher's comment was simply, "This is a really good idea. When you revise, focus on scoring the goal and how you felt while you were doing it." In the revision, the student focuses on the immediate events, his reactions leading up to scoring the goal, and his reactions upon the score. His use of specific sensory details and metaphor allow the reader to identify more closely with the excitement the writer must have felt as he was engaged in the particular action.

This revision is a total revamping of the writing. Studies of student revision indicate that they tend to be minimal at best (e.g., Bridwell, 1980). This young man's teacher has provided discourse knowledge and knowledge about developing content through a variety of activities. As a result, he clearly has the procedural knowledge to use his teacher's advice. He is able to focus on the experience, provide his reader with a good representation of his actions and responses, and create greater empathy in the reader.

When teachers do not understand the qualities of good writing as they appear for particular purposes and audiences, they will be unable to provide insightful and incisive comments to help their students improve writing. Worse, they may mislead students into ineffective writing. For example, had the teacher above not understood the importance of focusing to achieve impact, she might have suggested only that the student correct the punctuation of the dialogue. Such a suggestion might have resulted in correctly punctuated dialogue, but the impact of the writing would be no greater, and the student might have assumed that his lack of focus was good.

Where do prospective teachers learn about the characteristics of good writing? Once again, there are competing views of what makes a good argument, a good narrative, or a good analysis. Prospective teachers should probably become familiar with both criteria and the theoretical considerations underlying them. An excellent place to begin is Cooper and Odell's *Evaluating Writing: Describing, Measuring, Judging* (1977). More important, they need to see the value of studying student writing for its own sake and for what can be learned about the writers and their conceptions.

Content and Inquiry

In addition to knowledge of discourse, writers require knowledge of procedures for developing the content of writing. In Figure 1, that element is labeled "content." (Bereiter, 1980, calls it the "content processor.") In a series of careful studies, Bereiter and Scardamalia (1982) show that when youngsters come to school, they have the schema for conversation. One conversational turn by one partner prompts a comment by the other. In writing there is no conversational partner to prompt the processing of additional content.

Bereiter and Scardamalia (1982) point out that when young children are asked to write on a particular topic, they produce about as much as a normal conversational burst would include. When they are asked to say more, they produce about another conversational burst. Providing a series of "contentless prompts" indicates that children have far more content available for writing than they actually use. The process of recalling content for use in writing is probably one of the simplest of the content processing strategies. But it is one that children apparently need to learn.

A number of studies involve students in more complex kinds of content processing strategies and have shown powerful impact on the quality of students' writing (reviewed in Hillocks, 1986). Practicing such strategies appears to help writers inquire more effectively into the data they have available for writing and to transform it more adequately into the content of their writing. For example, some studies involve students in observing carefully and transforming sensory perceptions into language for use in writing. These students show large gains in the effective use of detail in later, independent writing (Hillocks 1979, 1982). Other studies involve students in analyzing data for use in developing arguments (in developing claims, evidence, warrants, counterarguments, and so forth). Students in these studies show large gains in developing arguments more fully and effectively (e.g., McCleary, 1979; Troyka, 1973).

All such studies strongly indicate the necessity of helping students learn and practice the strategies by which they may examine and transform data for particular writing tasks. A great deal of research and theory indicates that teaching knowledge of discourse structures alone is inadequate. Every secondary English teacher knows that students can study the conventional ideas about paragraph structure, learn to identify topic sentences and methods of development, but fail when it comes to generating interesting and adequate paragraphs of their own. This is the same problem that Janet Emig (1971) identifies in her complaints about the five-paragraph theme: it provides students a frame into which they can pour ideas; unfortunately, it allows the ideas to remain shallow. Successful and versatile writers need to know a variety of procedures for transforming data into the stuff of writing.

If that is true, then teachers of writing need systematically to incorporate into their curricula experiences in using such strategies. Increasingly, teachers realize, as do the participants in the English Coalition Conference, that students of writing need help "in mastering techniques for discovering and testing . . . information to develop ideas" (Lloyd-Jones and Lunsford, 1989, p. 21). *English for the '90s and Beyond*, the final report of the secondary strand of the English Coalition Conference (1987), puts the case even more strongly, stating that students must "learn to be inquirers, experimenters, and problem solvers" (p. 6) not only to become more effective writers and readers but to become fully participating citizens in a rapidly changing world.

Just what are the "techniques for discovering and testing . . . information"? What strategies are involved in the processes of inquiry--especially as they pertain to writing in various disciplines? Several models of inquiry are available, for example, Dewey (1910). Minimally, for teachers of writing, this writer believes that an adequate model of inquiry should include the strategies summarized in Figure 2.

This figure suggests that any inquiry appears to begin with observing (collecting and noting new information) or with accessing prior knowledge. Whichever comes first, the process of inquiry appears to demand a continual interplay between new information and prior knowledge. The process of observing and using prior knowledge leads naturally to either comparing or contrasting phenomena. Comparing, on the one hand, leads to generalizations about what is observed or what is known. Contrasting (noting differences or dissonances), on the other hand, leads to the definition of distinctions and to refining generalizations.

Both generalizations and distinctions demand analyses and explanations through inference, interpretation, and hypotheses. Accompanying these strategies, on the one hand, is the creative impulse to question and imagine what might be. That impulse has a centrifugal force pulling the inquirer farther from the data, but permitting new perspectives on what is there. On the other hand, the need to test and evaluate at every juncture has a centripetal effect, pulling the inquirer back to the data to test and evaluate observations, generalizations, distinctions and definitions, explanations and hypotheses. Most current textbooks do not reflect a model of inquiry. We can infer from Applebee's (1981) study of the teaching of writing in secondary schools that most teachers do not see inquiry as an important part of writing. Nevertheless, a great deal of current research, theory, and carefully considered professional opinion strongly support integrating strategies of inquiry with writing.

Many commonly assigned writing tasks demand the use of several of the strategies of inquiry outlined above. To write about a character in a literary work, for example, demands that the writer *observe* available evidence about the character; use *prior knowledge* in making sense of observations; *compare* the various bits of information in order to *generalize* about the character's behavior or values; *contrast* the same to find changes or anomalies; *question* the significance of what a character does; *imagine* what it might be like to be that character; hypothesize explanations of the character's behavior or significance; and *test* and *evaluate* all of these by examining new and old information. Even writing about a favorite place or person requires the strategies of *observation, comparison,* and *generalization*. Research projects and papers using primary source material (a practice recommended by increasingly more state guidelines) demand the use of the strategies of inquiry.

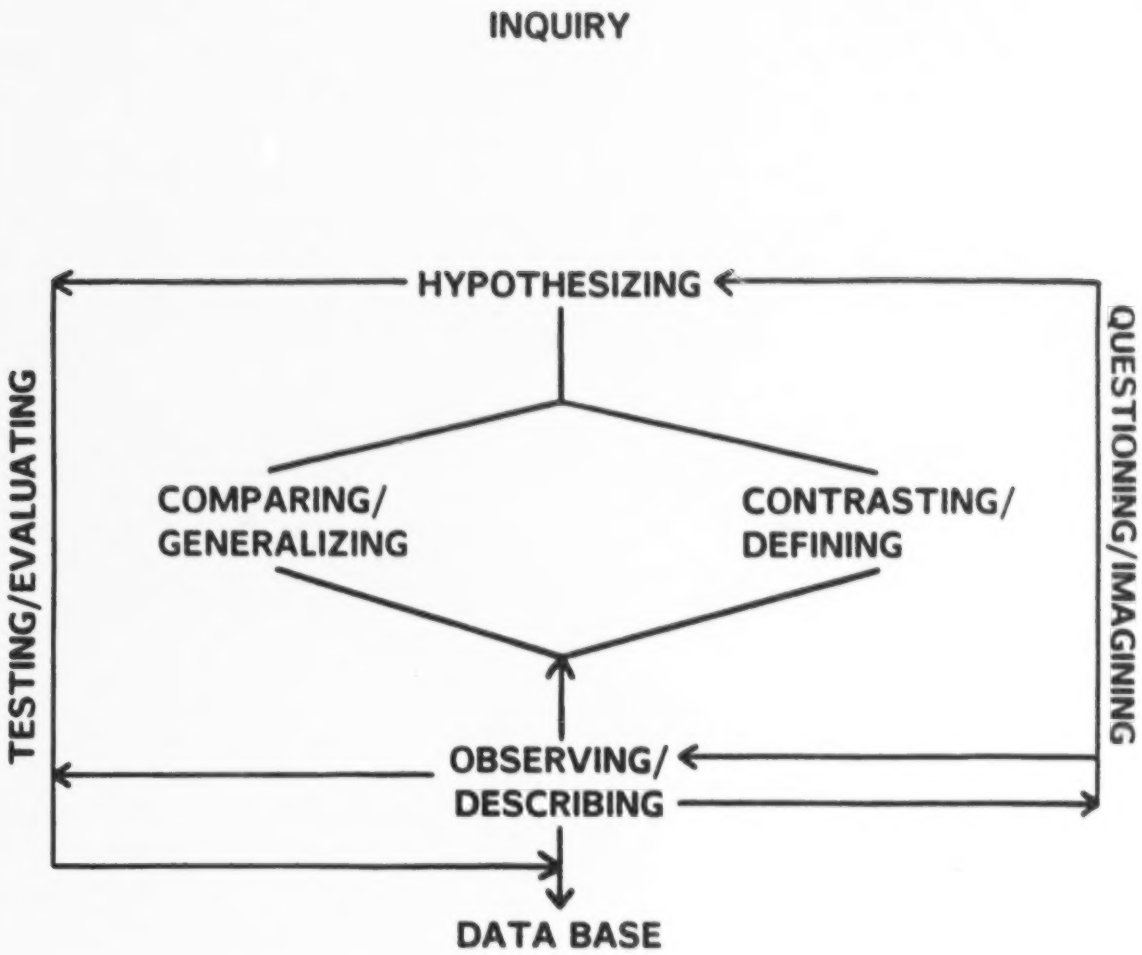

Figure 2. A model of inquiry (for developing content).

The Effective Teaching of Writing

Knowledge of discourse and strategies for inquiry, while necessary for the effective teaching of writing, are not sufficient. In addition, we need to ask what special pedagogical dispositions, understandings, and skills are necessary to help students learn strategies that will enable them to deal successfully with a variety of writing tasks in new contexts. Before proceeding to the specifics of teaching writing, it is imperative, I think, to comment on two dispositions that teachers must have to be successful. Although they are not exclusive to the teaching of writing, they are so important that I cannot ignore them here.

The first has to do with assumptions about the capabilities of students. A recent case study (Hillocks, 1989) examines the beliefs and instruction of two English teachers, one who believes her students have such extremely limited backgrounds that they are unable to deal with any but a text's most superficial meanings, and another who recognizes the difficulty his students encounter but assumes that with appropriate instruction they will be able to overcome it. As a result, the first teacher structures her classroom for the presentation of bits and pieces of information which she believes will develop students' background to the point where they will be able to comprehend what they read on their own. However, in her classroom, the comprehension required of students is minimal, focusing on literally stated main ideas and details, and ignoring implied meanings. In the first teacher's class, six students provide 85 percent of all student response. Sixty-seven percent of all student responses consist of three or fewer words. In short, students have a minimal role in the production of meaning in that class.

The second teacher, who assumes that his students will be able to work out meanings for themselves, structures the class to help students understand the literary problems they will encounter. The result is that all students contribute to the discussion. Only 14 percent of student responses consist of three words or fewer. Indeed, 47 percent of student responses are more than one line long. More important, students construct complex meanings for themselves and come to understand sophisticated literary concepts.

If we assume that students are unable to learn any more than the most simplistic material because they have very weak backgrounds, we will tend to adjust our teaching to that level. As Cohen (1988) points out, this attitude helps us confirm our success as teachers. If we assume, in contrast, that students can learn and if we adjust our materials and activities so as to prepare them for more complex concepts and tasks, we will find that they reach eagerly to deal with tasks that before were obscure.

The second assumption is closely related to the first. We have to assume that teaching is a deliberative activity, open to reflection, assessment, and revision. If we assume that teaching is deliberative, we assume that we can change it to help learners learn more. If, in contrast, we see teaching as formulaic (going through a set of predetermined activities

without regard to their immediate effects), then we assume that what we do as teachers makes little difference to the learning of our students.

Given these two assumptions--that our students can learn more and that effective teaching involves deliberation--we can look more closely at the main business of teaching writing: to help students learn strategies that will enable them to deal with a variety of writing tasks in new contexts. Learning strategies for use in new contexts means learning procedural knowledge.

Teaching Procedural Knowledge

Psychologists discriminate between declarative knowledge and procedural knowledge, knowledge of what as opposed to knowledge of how. We may have declarative knowledge of Beethoven's "Pathetique Sonata" from having heard it many times. We may recognize it from as little as two or three successive bars. We may be able to describe its movements and tempos, but all this is declarative knowledge. The knowledge necessary for playing it is procedural and involves minute bits of information about how to press and hold piano keys, how to move from one chord to another, how much pressure to give keys for notes appearing in the melodic line, and so forth. Most such information is neither taught nor learned in verbal form. Rather, the knowledge necessary is modeled by the teacher, approximated by the student, coached by the teacher, and developed in process over a period of time in a variety of simpler contexts. When teachers believe students are ready for the "Pathetique," they demonstrate, coach, break it down into manageable parts, focus on even as little as some portion of a single measure at a time, and then encourage synthesis of the whole.

The procedures involved in writing are even more complex, for the writers must invent their own scores. Just as we would not expect a pianist to learn a complex sonata simply as the result of hearing several outstanding performances (declarative knowledge), we cannot expect writers to learn from models or the rules invoked in teachers' comments. Procedural knowledge must be learned *in process*--but with the help of models, coaching, and the facilitation that comes through making tasks manageable and varying the contexts in which they are learned.

Figure 3 illustrates the effects of concentrating on certain kinds of declarative knowledge as opposed to procedural knowledge. This figure represents some of the findings of a meta-analysis of composition studies (Hillocks, 1986). The first two foci of instruction, grammar and models, both concentrate on declarative knowledge. In the case of grammar, the pertinent knowledge has to do with the names of parts of speech, parts of sentences, types of sentences, and so forth. In treatments focusing on model compositions, the declarative knowledge was of organizational structures in compositions, the nature of introductions and conclusions, the use of evidence, and so forth. Students read the writing of other writers to see how they had handled the problems confronting them. Declarative knowledge of the patterns observed was expected to act as a guide for student writing.

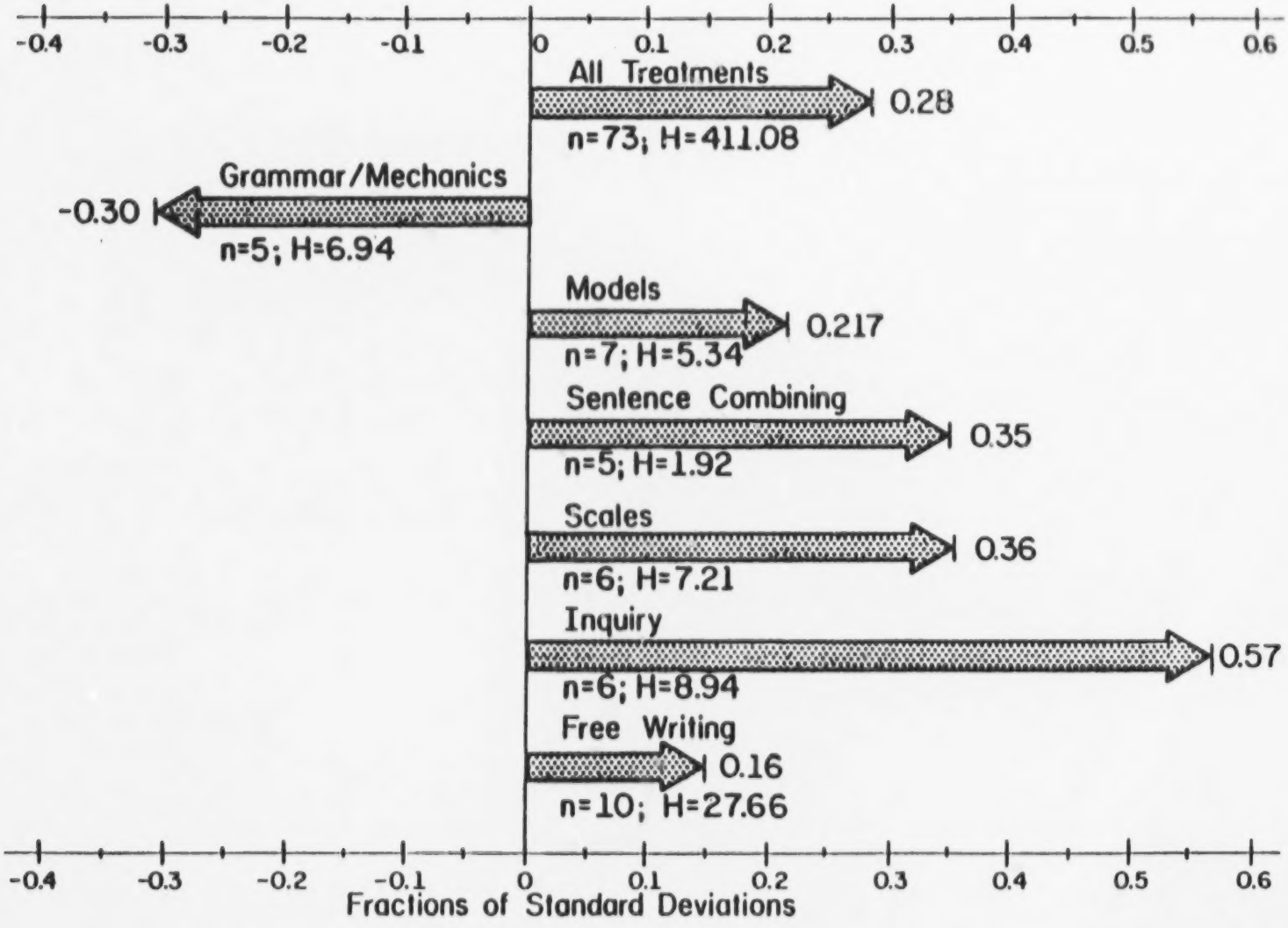

Figure 3. Focus of instruction--experimental/control effects.

The remaining four treatments may be regarded as focusing on procedural knowledge. Sentence combining provides students with practice in manipulating a variety of syntactical structures in many different contexts. The "scales" treatments ask students to apply sets of criteria to various pieces of writing, make judgments about the strengths and weaknesses of that writing in terms of the criteria, generate ideas for improving weaknesses, and make revisions using the criteria and the information generated. The inquiry treatments focused on learning particular strategies for transforming raw data into the content of writing--the strategies of inquiry outlined earlier in this paper.

The category of free writing incorporates most studies that made use of the general process of writing (prewriting, drafting, revising, receiving feedback, and editing). Figure 3 presents the effect sizes for these treatments (the difference between the experimental treatment and their control treatments expressed as a portion of a standard deviation). Clearly, the two treatments which focus on declarative knowledge, grammar and models, do much less to enhance the quality of student writing than the three procedural treatments which focus on specific strategies. The fourth procedural treatment, free writing, which focuses on general process elements of writing cannot, in itself, be expected to have a powerful impact on the quality of writing. Although it presents general processes which students surely need to be aware of, it does not provide specific information necessary to the successful operation of subprocesses demanded by particular writing tasks.

Undoubtedly each focus of attention makes some contribution to helping students become better writers. Even a knowledge of usage and the conventions of mechanics come into play at lower levels of the composing process: the production of graphemic units and editing (see Figure 1). Successful teachers of writing do not use one of these foci of instruction exclusively. All or most are integrated.

Planning, Reflection, Assessment

Many highly successful treatments reflect careful selection of materials (both models and sets of data for analysis) and sequencing so that students use strategies in highly supported situations, moving to new contexts with less teacher and peer support (e.g., Faigley, 1979; Hillocks, 1979 and 1982; McCleary, 1979; Sager, 1973; Troyka, 1973). All of these treatments allow students to concentrate on some part of a complex writing task before independently undertaking the task in all of its dimensions. In addition, when students undertake a new task, the instruction provides a high level of support in terms of modeling, teacher coaching, peer support, and so forth.

Sager's (1973) experimental treatment, for example, sets out to teach students a set of criteria (or scales) used to guide their own writing. Obviously, this is a complex task which includes learning what the criteria are, how to use them to make judgments, how to use the judgments to prompt better writing, how to generate the improvements, and how to synthesize them in writing. In Sager's treatment, students gradually undertake more of these tasks independently and in new contexts. At the beginning, teachers explain the criteria and

lead students in applying them to selected compositions, discussing weaknesses and ideas for improvement. Next, students work in groups applying the criteria to selected pieces of writing and generating ideas for improvements. Then each student synthesizes the ideas generated by the group to revise the composition. Eventually students proceed with these tasks independently.

During the course of instruction, the tasks change from relatively simple to complex, students move from dependence to independence, and students have many opportunities to apply what they are learning in new contexts. At the same time students are working with whole pieces of discourse rather than with the isolated bits of discourse that appear in worksheets and that have little meaning for anyone. A large body of empirical evidence from cognitive psychology provides strong support for these ideas about learning transferable strategies and helps to explain how and why such instruction works (see, for example, Bereiter and Scardamalia, 1987, especially pp. 254-256, and Bransford, 1979, especially pp. 205-245).

Planning. As suggested above, one of the most important dimensions of planning--especially for complex writing tasks--is the careful analysis of the task to reveal its dimensions and problems. Such analysis permits treating complex tasks in manageable parts and leads to the selection of materials of various kinds intended to help students learn and practice the dimensions of the task. McCleary (1979) and Troyka (1973) base instruction on an analysis of argument. Focusing on ethical argument, McCleary's treatment systematically introduces students to the concepts of principles, exceptions, obligations, consequences, and so forth. Students then identify the obligations, consequences, and principles in certain ethical controversies. They then work at identifying and analyzing these concepts in a variety of ethical problems and developing appropriate arguments about them.

Troyka's (1973) instruction recognizes the importance of predicting opposing points of view and their attendant arguments in order to find a solution through compromise, to structure one's own position more clearly, or simply to counter the opposing points. Both McCleary (1979) and Troyka recognize that effective arguments are based on specific situations and particular sets of data. Accordingly, their instructional materials provide situations and sets of data for students to examine in developing arguments.

The analysis of a writing task will address questions related primarily to discourse as well as questions related primarily to substance. In other words, what will a writer have to know about discourse and about the processing of data or content to accomplish the writing task successfully? To write a fable, for example, a writer must know that a fable consists of a story plus a moral (and that sometimes the moral is implied), that the characters are often animals who talk and act as human beings, that at least one animal usually represents some human foible, that the plot often reveals the foible in the animal, and that the moral grows out of and comments upon the story. Knowing what a fable is, however, is a necessary but

not a sufficient condition for writing one. Writers must also be able to generate appropriate ideas. Analysis suggests three possible directions for developing fable ideas: (a) begin with a moral, attempt to find a situation to illustrate it, think of animals to fit the situation, and so forth; (b) begin with a situation in which one character behaves foolishly, think of an animal to take the part of that character, and so forth; (c) begin with an annoying human quality, think of an animal that might symbolize that quality, generate ideas about how that animal might treat others, think of ways his actions might bring about his own downfall or embarrassment, generate a moral.

This analysis suggests that teaching students to write fables will involve not only teaching what a fable is, but how to generate ideas for developing a fable, using one or more of the sets of ideas listed above. (Experience indicates that the third helps more students produce better fables more quickly.)

A second step in planning involves the selection of materials: models and data sets. Ordinarily, good models for use in instruction are those which clearly illustrate the salient features of the kind of writing in question. But they must be accessible and interesting to students. The second kind of material--what I call data sets--does not appear in most textbooks. However, in the meta-analysis alluded to above, instruction that uses data sets to help students learn strategies for coping with the substance of writing (inquiry) has greater impact than the other foci of instruction. In the case of argument, for example, both McCleary (1979) and Troyka (1973) present cases of controversial situations with relevant data. Students must learn to generalize about the data presented, analyze the situations, make predictions about the audience, select the data that will support generalizations appropriately, and so forth.

The teacher selects data that are likely to be of interest to students and that provide them with common material to analyze and discuss. Having common material allows students to develop and try arguments with their peers, who are equally knowledgeable about the situation. When students do not have a common knowledge base, they may be unable to formulate their own ideas from real information, support generalizations, predict opposing points of view, and so forth. They cannot experience delivering an argument to others who have comparable information but a different perspective and who can serve as a critical audience.

In addition to selecting materials, the teacher must also design effective activities in which the students can come to understand and actively use strategies required by the writing task. These include effective initial teacher-led discussions to introduce new strategies and information, small-group discussions in which students help each other to apply strategies to new problems, as well as group and individual activities for writing, revising, and feedback. The most effective of these activities focus attention on specific strategies, facilitate learning by allowing students to work with some part of a complex strategy, and vary the contexts for

use. (For solid examples, see Kahn, Johannessen, and Walter, 1984; and Smagorinsky, McCann, and Kern, 1987.)

Finally, teachers must sequence the materials and attendant activities to move students from dependence on the teacher, when information and strategies are new, to independence as students gradually gain knowledge and experience. This sequence may first focus on producing certain parts of a complex writing task so that students can concentrate on one problem at a time when the task is relatively new. For example, students might focus on writing dialogues between characters in conflict before writing a full short story. The sequence may allow students to practice certain strategies of inquiry in a variety of supported contexts before requiring them to use the strategies independently in some new context. For example, in learning to generate criteria, students may begin by using supplied criteria to classify examples, then contrast supplied examples to generate criteria, and finally generate both examples and criteria independently, each of these in a new context. (For an extended discussion of such a sequence for teaching definition, see Johannessen, Kahn, and Walter, 1982.)

Assessment and reflection. The kind of planning suggested here is an art requiring assessments and judgments about students and their capabilities, about materials and the problems they may involve, about the strategies required in a writing task, and about how students interact with materials and activities to become independent. It is an art that requires considerable reflection at every stage of planning, teaching, and assessment. Even while teaching is in progress, teachers should be able to monitor the activity as it develops, watch for difficulties that students encounter, and make changes as necessary. Such teaching requires active use of the kinds of knowledge discussed above under "The Territory of Writing."

For example, one student teacher recently asked a group of low-achieving students in a Chicago public school to examine a set of data with an eye to selecting statements which supported one of two different arguments and to explain how particular data supported that proposition. She saw from student responses that they were unable to distance themselves from the data in order to make those deliberate judgments. Immediately, she changed the assignment, asking them to select the data that they believed would support their own personal point of view and to explain why. The activity went forward without further difficulty, maintaining the interest of the students at a relatively high level.

In teaching fables, one teacher noted that beginning with morals proved particularly difficult for seventh graders. He switched immediately to brainstorming for human frailties, qualities or behaviors that students resented in others. The students suggested such things as "talking about you behind your back," "telling secrets," "pretending to like a person that you really didn't like," and so forth. Reflection at this crucial moment in the teaching process enabled the students to go on to produce successful fables.

In other words, for assessment and reflection to be productive, they must be involved at every step of the teaching process, examining both the effect and the value of teaching. Teachers must not only ask whether students have learned to write fables, arguments, or effective narratives, but whether those learning experiences have had real value to the students as writers and as people. Only by asking such questions persistently can we expect to develop effective curricula in writing. And by asking them persistently, we can continue to develop our knowledge about the teaching of writing.

Teachers of writing, then, need more than a theory of discourse and knowledge of writing processes. They also need to know procedures for analyzing writing tasks, for inventing materials and activities, and for assessing the effectiveness of their own inventions both during teaching and following it. In this sense, the teaching of writing is an art, but one which is learnable and open to examination through a variety of analytic tools.

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TEACHING/WRITING IN A COMMUNITY OF INQUIRERS[22]

John T. Gage[23]

The question we are addressing--"what teachers should know about writing"--may imply that there is a stable body of knowledge "out there" and, if we could just say what it is, that all teachers need is to possess it. Such is not the case. The field of composition is so diverse at the present time, so cluttered with competing methods and ideologies, that it is impossible to claim or to practice a pedagogical approach to writing without at the same time assuming a part, whether actively or passively, in the energetic debate that characterizes the field. There is no consensus. Out there, among the composition theorists, there is considerable division and not a few axes to grind. Rather than knowledge of the sort that can simply be taken in and applied in practice, the field is in fact constituted by competing and incompatible claims for teachers' attention and allegiance (see, e.g. Berlin, 1987; North, 1987). Some are alarmed by this state of affairs, claiming that without the possibility of hard knowledge and shared agreement about what we are teaching and how we are teaching it, students will suffer by being taught by whatever approach happens to be blowing in the wind. Others are more at peace with it, finding the strongly debated issues that characterize this field to be evidence of its health and of a pluralism that is finally desirable for a discipline that deals with central questions about learning and knowledge.

I will try not to use this occasion to defend my side of whatever issues I generally debate when I write and speak about teaching composition, though I will inevitably present parts of it to you. The question that we are all addressing cannot be answered by the proliferation of specific theories or pedagogies, but only by addressing certain assumptions about our field that provide the only possible test of whether any theory or pedagogy, in the vast array of those available, makes sense. But assumptions are difficult to articulate because, like chemical and metabolic processes in the body, they are taken for granted, they derive from ideological or conceptual givens that are mostly unargued when scholars say what they think. Assumptions are what we think *with*, not what we think *about*. So, it is unlikely that I will succeed in identifying the actual assumptions that govern the views of writing that I will be discussing. What makes it most difficult is that the question of "what teachers should know" raises for me the even more perplexing question: What does it mean

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[22]Parts of this talk will appear in a larger, more formal, essay entitled "A General Theory of the Enthymeme for Advanced Composition" to be published in *On Teaching Advanced Composition* (Boynton/Cook), edited by Katherine M. Adams.

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to *know* anything? In the face of this awesome question, you will find me coming around, eventually, to a plea for tolerance and pluralism. Even as I say this, however, I am haunted by the possibility that pluralism itself may go too far, as the poet J. V. Cunningham (1970) expressed in this epigram:

> This Humanist whom no beliefs constrained
> Grew so broad-minded he was scatter-brained. (p. 117)

Negotiating between the extremes of true belief in one method and not having any means to discriminate among methods is no easy task. The position I will defend, finally, is that what a writing teacher needs to know is how to live with the condition of uncertainty. And this, I also think, is what learning to write is all about.

"Either/Or Thinking"

My own work in the field of composition has been to promote methods of writing that develop habits of inquiry. I will say a bit more about this shortly. Reflecting on what this means in relation to the field of composition theory and pedagogy leads me to think that a significant impulse behind my work has been to try to negotiate between extreme views. Writing pedagogies are particularly susceptible to something I will call "either/or thinking." One method is proposed as an alternative to another and the teacher is asked to choose. The word *alternative* appears so often in the advertising for writing textbooks that in order really to distinguish a new book from the pack one would have to advertise it as "no alternative at all; just more of the same old stuff."

What are some of these alleged alternatives? I will write them large, risking little exaggeration, however. "Expression," for instance, is pitted against "competence" as two mutually exclusive aims of teaching writing, each of which will generate incompatible pedagogical practices. Teaching formal competence by direct means is often viewed as an obstacle to expression, for instance. "Creativity," with its attendant stress on the values of imagination and personal narrative, may be pitted against "exposition" or "argumentation," with their attendant stress on formal models and logical formulae. Writing teachers may speak of a new emphasis on "process" as an alternative to a discarded view of writing as "product," as if it were possible to have one without the other.

And the most recent example of "either/or thinking" is found in the recent career of E.D. Hirsch, who in the 1970s advocated the teaching of imitable sentence patterns that might be abstracted entirely from any particular content. Hirsch in the 1980s repudiated that idea entirely and substituted for it a pedagogy focused exclusively on content: the cultural information, in the form of "facts," that literate readers and writers must have in common in order to communicate. *Either*, it seems, one teaches empty forms that constitute the

technical competence of skilled writers, *or* one teaches the contextless information that Hirsch can organize into an alphabetical list and best-selling "dictionary."

Choosing Sides Leads to Distortions

In the presence of such compelling dualisms, it seems necessary to make a choice. In practice, this tendency to have to choose up sides leads, I believe, to distortion. It is the side that one does not choose that will be distorted to guarantee that one's own position will look good. Those who, for instance, are persuaded to become advocates of the new emphasis on "process"--although they too will disagree about what this means--have constructed a "straw man" and named him "product," a term that has come to signify radical intolerance of all the errors in formal student writing as if transgressions of civil law. Similarly, those who are persuaded to become advocates of "expressive" writing are tempted to accept extreme characterizations of formal models or logical principles as impersonal and restrictive. One hears and reads phrases such as hegemonic, patriarchal, logocentric, life-killing.

In contrast, some who advocate argumentative writing have constructed a "straw man" out of "expression," and one hears or reads of him described as anti-intellectual, fuzzy-minded, undisciplined and merely emotive. Choosing sides, then, becomes a potentially destructive activity, since it may blind one to the virtues of another's approach in the rush to discover its limits. Such debates can quickly degenerate into name calling. I am a liberal-minded advocate of consensus and quality; you are an irrationalist. I am a feminist after recognition of difference and subjecthood for the powerless; you are an authoritarian grammarian in the service of prevailing power relationships. Labels that shut off rather than encourage inquiry. And in the process of rejection, which goes along with strident advocacy of one or another extreme, any value that might be found in opposing viewpoints goes unacknowledged and undetected.

Process of Rejection

I once used a mixed metaphor to characterize this process of rejection. Actually I abused two clichés at once by combining them. I called it "throwing out the straw baby with the bathwater" (Gage, 1984). The occasion for my creation of this barbarous accretion was a review of a book about composition pedagogy that seemed to me, at the time, to illustrate the dangers of either/or thinking in this profession. The book was innocently titled *Rhetorical Traditions and the Teaching of Writing* (Knoblauch and Brannon, 1984) and in fact I agreed wholeheartedly with its conclusions about the teaching of writing. Here is the authors' summary of their conclusions:

> The basic features of a classroom predicated on assumptions of modern rhetoric are the following: (1) It's student centered rather than teacher

centered; that is, its agenda is students' own writing and their development as writers, not a teacher's prescriptions about writing or a contrived time-table for that development. (2) It assumes that composing is a competence which develops through use, not a system of skills to be serially introduced through lecture/discussion and then practiced one-at-a-time in drills and exercises. (3) It is facilitative, not directive, and collaborative, not authoritarian; that is, teachers join in the process of making and responding to discourse in order to sustain students' composing by implicating themselves in the guesswork, exploration, and reformulation in which all writers engage. Rules and other absolutes disappear in favor of repeated acts of writing and continuous, collegial responding which assumes, in part, that other students' reactions can be as relevant as the teachers and that *all* responses are valuable, useful, individual impressions to be weighed in rewriting while *none* are ultimatums for revision. (4) It reverses the ancient priorities of correctness, clarity, and fluency out of conviction that writers who have not learned to value their meanings by seeing how others value them have no reason to develop, indeed lack the basis for developing, any special expertise in their transmission. In light of these four basic features, the writing workshop is attitudinally distinct from the traditional classroom, and therefore irreconcilable with a traditional approach. It's an environment in which everyone, beginning with the teacher, is a writer and also a reader. The governing spirit of the writing workshop is the modern rhetorical perspective, where writing has heuristic value, where writers search for ways to organize experience as coherent assertions and patterns of assertions, where authentic purposes and intended readers guide the choices about what to say, as well as where and how to say it, where revising is perpetual in the search for meaning, and where individual creativity, the energy of personal statement within a community of interested readers, is more valuable than timid or enforced capitulation to hackneyed thought. (p. 104)

Labels Applied

This is indeed a noble enterprise, and one that teachers of writing would do well to understand and to apply. I will in fact be advocating many of the same values later in this talk. When I say I agree wholeheartedly with these conclusions, however, I mean that I agree with the positive side of what are expressed always as binomial choices. But I pause when I reflect just what it is that these authors require me to reject in order to join them in the choices we embrace together. Notice that the paragraph I have quoted is built on the rhetoric of antithesis: its form is to assert "*this*, but not *this*." The form requires us to assent to certain values at the expense of other potential values. Of course the rejected values are presented in language that is loaded to make them unacceptable: "*contrived* time-tables for . . . development," "a *system* of skills . . . practiced *one-at-time* in *drills* and exercises," "not *directive* . . . not *authoritarian*," "rules and *other absolutes*," "*ultimatums* for revision," "*ancient* priorities," students "have *no reason* to develop," "*irreconcilable* with a *traditional* approach," and finally, "*timid or enforced capitulation to hackneyed thought*."

Exactly what practices or pedagogies are being characterized by these labels? Whatever they are, the uncritical reader of this passage is invited simply to trash them, and they include nearly everything that may have constituted good and effective teaching of writing in the hands of good and effective teachers at one time or another. So the invitation here, on behalf of embracing a student-centered, collegial, supportive classroom in which students write meaningfully and responsibly, is in fact an exhortation to throw out any informed application of techniques from the past. While there is a lesson here for teachers who apply such techniques thoughtlessly, I pity the teacher who would read such a list and choose to remain ignorant of all the potential knowledge contained in what these authors call the "tradition" in favor of a so-called "modern" classroom in which there is nothing left for the teacher to teach and anything goes. Talk about absolutes! This passage is full of them.

Partial Readings of History

So, while I want to assent to the conclusions these authors reached in their book, I can only do so by reacting critically to the reasons they presented for them. I will paraphrase now the logic of their central argument: The traditional way of teaching writing (such as one finds in most textbooks) relies on categories and assumptions inherited from the ancient rhetoricians. Ancient rhetoric depends on an epistemology in which Truth (big *T*) exists apart from language and in which language serves to dress that truth up and make it palatable for an audience of dupes. But modern epistemology, since Kant, has situated truth (small *t*) *in* language, so that meaning is a construct of words and subject therefore to interpretation but not to verification outside language. So, if the traditional teaching of writing is based on an epistemology that has been rejected in the modern world, that way of teaching writing must be rejected in favor of one based on this new epistemology, in which students must be free to discover new meanings through language rather than bound to pass on old meanings through language.

The authors have based their entire case on a reading of history that is partial and absolute. It is absolute because they see everything thought about language before, say, Kant as wrong, while seeing everything thought about language since Kant as true. (I trust you catch the irony.) This watershed theory of the history of rhetoric is partial because it distributes into "ancient" and "modern" two views of language that in fact coexisted in ancient rhetoric just as they coexist in modern rhetoric. I can't give you a full demonstration of this here, but I can jump to the consequences.

To ignore the fact that the ancient rhetoricians debated exactly the same epistemological differences that these authors wish to see as marking the difference between ancient and modern thought, easily turns into an excuse to remain ignorant of the tradition of ancient rhetoric and all of the potential knowledge that it might contain. The roots for

a modern epistemology of language derive from those ancient debates, even though *some* parts of ancient rhetoric are also just as corny as these authors say they were. And to remain ignorant of the traditions that inform the controversies of one's own time is to deprive oneself of a means of thinking about the similar controversies that are present during one's own time. This is the consequence, I am afraid, of such a dualistic view of history, a reading of the history of rhetoric in which all real knowledge about language is called "modern" while the "tradition" represents nothing but lore and superstition and can only be accepted as "authoritarian," "directive," and a "recapitulation of hackneyed thought." You must be either on the side of modern angels or in league with the traditional devil. My portmanteau cliché "throwing the straw baby out with the bathwater" may not be eloquent but it is descriptive.

A Critical Attitude Is Needed

I suppose that this implies a lesson for the teacher of writing, and that is that one should know something about the history of one's own discipline. It is only by having some independent knowledge of Plato, Aristotle, Cicero, Quintilian, Locke, and Kant that one would be able to assess the accuracy of statements made about these same thinkers asserted by the authors of the book I have been traducing. And it is only by knowing what the issues and arguments of these thinkers were that one can identify the same issues and arguments when they recur in contemporary controversies about teaching writing (see, e.g. Gage, 1986). But I am not taking this position here, since the idea that every teacher of writing needs to be a scholar of the history of rhetoric is not only impossible and unrealistic, but unnecessary. While the teacher of writing can only benefit from knowing about the history of rhetoric and composition, this knowledge alone is no guarantee of anything, any more than knowledge of all the contemporary rhetoricians who advocate different and contradictory positions can guarantee good teaching if the teacher lacks the critical ability to assess these positions for him or herself.

All that is needed to see through the arguments of the book I have dealt with is the knowledge that they *are* arguments. To read such a book critically, one does not need to assent to its invitation to think in an either/or mode. One can reserve for oneself the ability to say "yes, but . . ." As much as I respect Tom Romano's idea of the teacher-writer expressed earlier in this volume, I would like to advocate the idea of the teacher-*inquirer*, not as an alternative but as a prerequisite.

So, rather than saying that there is any particular piece of knowledge about the history of rhetoric or about modern pedagogy that a teacher must have, I am saying that a critical *attitude* is what is most needed. I will say some more about what this attitude is like and how I think it can be learned and try to apply it to the teaching of writing.

Where Critical Judgment Comes From

There is an essay I particularly admire and that, if it were in my power, I would have every teacher of writing--of *anything*--read. It was written by Wayne C. Booth (1970), and it is called "The Uncritical American, or, Nobody's from Missouri Any More." Of course this is not the only essay that might present teachers with the issue of where critical judgment comes from, and others may want to think instead about the same issues in the context of some favorite piece by Dewey or Bruner or William James or Peter Elbow or Hannah Arendt. Anyway, Booth defines critical judgment as the act of assessing "the adequacy of the *case made* to the *conclusions*," (p. 65) or knowing "how to match the degree of [one's] convictions to the quality of [the] reasons" (p. 73). I wish now to make several observations about this definition.

First, as Booth points out, the necessity of making this kind of judgment is our "common lot." All of us, teachers or students, females or males, romantics or rationalists, poets or scientists, are constantly engaged in the activity of judging reasons, whether they are the reasons of others or our own. Even if we cannot give a definition of what makes a good reason--and I think most of us can't--we nevertheless apply criteria implicitly whenever we accept or reject a reason, whether it is one we hear or one we might choose to offer.

Second, we all understand somehow that it is possible to judge reasons well or to judge them poorly and that we are all equally guilty of doing both on occasions, depending, for one thing, on the degree to which we *want* to accept a conclusion. We all know, then, that since we have been wrong about such judgments in the past, the possibility of being wrong about them again is ever present.

Third, we have learned whatever we know about this process by doing it. We do not apply a memorized rule each time we make such a judgment. We apply instead a set of tacit standards that are in fact very complex and that we have learned just as we have learned the so-called rules of grammar: by active participation in the activity of making sense of our own and others' arguments.

Fourth, this definition implies a standard for assent that denies the possibility of closure in the discussion of any issue. What I mean is this: If we are obliged to measure the *degree* of our convictions against the *quality* of the reasons offered for them, then we have defined conviction as subject to degree. Many are accustomed to thinking of conviction as if it were a light switch having an "off" position and an "on" position: Either I hold a conviction or I do not. But this shift toward judging the adequacy and quality of reasons makes that analogy inappropriate. Having convictions, according to this way of thinking, resembles a rheostat more than a switch. Assent is possible *up to a point*, or *in so far as* the reasons are adequate. This attitude yields judgments that are real, but nevertheless subject to change (in either direction) if better reasons come along. It assumes that new reasons with the potential to change the degree of our convictions are always possible. And so it is

this attitude that enables one to *consider* the reasons of others when they are offered to us, that justifies our willingness to inquire further into issues on which we already have convictions, and that promotes the free and tolerant exchange of ideas and reasons between people who hold different convictions.

Fifth, and finally, this definition of critical judgment reorients us to the idea of knowing and what it means. Knowledge in some absolutist terms (and I do not reject the possibility of such knowledge in some areas) we are accustomed to think of as a *commodity*, something that can be packaged and traded and remain essentially stable in the interchange of minds. But what I have been describing seems to me to transform our understanding of knowledge from a commodity to an *activity*. That is, as something that we *do*, rather than something we *possess*, and that we do together, in discourse, when we reason. The kinds of reasons we create and the degrees to which we accept them, in other words, are not conditioned solely by rules and private understandings but are subject to the convictions, reasons, experience, and values of those other members of the inquiring community in which we interact. So that what one is able to believe is a result of the thinking that we have done together. It is a performance, a drama, we enact together.

The Poet's Version: The Metaphorical Process

Lest you think that the process I am describing, because I have emphasized the term "reasons," is based on logic, let me turn from the definitions of a rhetorician to the testimony of a poet. Another essay that I would have all teachers read, were it in my power to command, is by Robert Frost (1966), a talk he gave called "Education by Poetry." In it, Frost says he wishes to "go further and further into making metaphor the whole of thinking" (p. 37), and he illustrates how ideas that we take for granted originate in metaphors, a process of implying that one thing is somehow like another. Thinking is relational in this way. This means, of course, that such thinking seems valid only to the extent that we recognize the limits of such relationships, so that, as Frost says,

> unless you are at home in the metaphor, unless you have had your proper poetical education in the metaphor, you are not safe anywhere. Because you are not at ease with figurative values: you don't know the metaphor in its strength and weakness. You don't know how far you may expect to ride it and when it may break down on you. (p. 39)

He illustrates this process of a metaphor breaking down like this:

> Somebody said to me a little while ago, "It is easy enough for me to think of the universe as a machine, as a mechanism."
> I said, "You mean the universe is like a machine?"
> He said, "No, I think it is one . . ."

I asked him, "Did you ever see a machine without a pedal for the foot, or a lever for the hand, or a button for the finger?"
He said, "No--no."
I said, "All right. Is the universe like that?"
And he said, "No, I mean it is like a machine, only . . ."
"It is different from a machine," I said. (p. 40)

So if thinking is like a metaphorical process, creating relationships between one thing and another, what one learns by studying metaphor, Frost says, is that you have to know when it breaks down, a matter of judging the adequacy of relationships. And, like Booth's idea of critical inquiry, Frost's is meant to be a process that opens up possibilities rather than shuts them down.

> We ask [students] in college to think, [he says,] . . . but we seldom tell them what thinking means; we seldom tell them it is just putting this and that together; it is just saying one thing in terms of another. To tell them that is to set their feet on the first rung of a ladder the top of which sticks through the sky. (Frost, 1966 p. 41)

I could draw from Frost's statements about thinking as metaphor the same consequences that I itemized in the case of Booth's definition. Let me merely add one more, however, that will return me to my theme of either/or thinking. Such a view of the process of creating ideas, and of recognizing their potential limits at the same time as we recognize their potential strengths, destroys the neat dichotomy between "creativity" and "rhetoric" that characterizes much talk about composition; that is, it suggests that all thought is creative thought--even that which is bound by the constraints of form--and at the same time acknowledges that conditions of judgment pertain to all arguments, whether overt or implicit in the form of expressive or metaphorical writing. Writers must create, and they must subject their creations to judgments based on conditions of communal assent. The choice between creative or expository writing, to bring the matter down to curricular earth, is a false choice, since each is necessarily present in the other. Each can, and should learn from the other, but if they are seen as mutually exclusive alternatives this not likely to happen.

Having reinvented Aristotle's Golden Mean, I suppose, I could go on to show that this process of struggling creatively within conditions of constraint, and its relation to knowledge as a performed activity that is contingent on communal acts of judgment--that this process is present in even the earliest treatises of the ancient rhetoricians and is more or less present in all but the most practical and reductive theories of composition today. But I will forgo this analysis and turn instead to the original question, What should a teacher of writing know? Let me tell you a little story.

What Should a Teacher of Writing Know?

I was addressing a group of high school teachers once and arguing, as I have been doing indirectly here, that students of writing must see themselves as part of an inquiring community, that they must write about ideas that are their own, in response to genuine issues subject to different positions, and that they must find reasons that acknowledge the possible reactions of those other members of the community of inquiring minds in which they participate as they compose. I cautioned that the students would find this process difficult because it means that they must think for themselves when they encounter issues that have no obvious answers. One of these teachers in my audience became very excited because she said that what I was saying reminded her of her first experience in a college-level composition course:

> My professor had us read *Hamlet* and then assigned us to write on the question of whether Hamlet is an Aristotelian tragic hero. I panicked and went back to my room and cried because I couldn't think of anything to say. So I went back to the professor and told him that I couldn't write the paper. He asked me if I had read the passage from Aristotle's *Poetics* that he had also assigned, and I confessed that I hadn't. He told me to read it and then see if I could answer the question. I read the *Poetics* and found the answer and got the paper done.

I thought this was a wonderful story, so I asked her what difference this experience had made to her, how it affected her teaching of English to high school students. And then, very sincerely and emphatically, she replied: "No student of mine ever leaves my class without knowing the definition of an Aristotelian tragic hero!"

Here in this anecdote is, I believe, the core of our problem. Here is a teacher, at least in this response, who values easy answers over hard questions and who seems so uncomfortable with the struggle with uncertain ideas that she would protect her students from that struggle. Yes, we can teach students such definitions, just as you can give them formal models of essays to imitate, but we may do so at the cost of teaching students to take less responsibility for their own thinking. Students take more responsibility for their own thinking if they are asked to respond, with what they know and can find out, to issues that do not have obvious and absolute answers, for this process requires them to think about reasons and to judge them critically against the convictions and reasons of others. Only such a communal process can produce the sense of responsibility, for what one says and for the reasons that one offers, that will produce genuine inquiry in the writing and reading that students will do after the composition class is over. Lest I be accused of either/or thinking myself in this statement, however, let me add that this process, which is open-ended and

unpredictable, may be *guided*, if not *governed*, by principles of form and rationality that may be taught and learned in the process of using them.

Teachers Should Engage in Active Inquiry

The issues that are being debated in composition pedagogy today are issues that have no obvious or absolute answers. This situation, rather than being a problem, constitutes an opportunity for teachers to engage in the kind of critical inquiry that they should be encouraging in their writing students. For teachers to encourage this kind of active inquiry, they must themselves be engaged in performing it. They learn to do it, after all, in exactly the same way that students do. Just as students do not learn this process by reading about it in a textbook but must become actively engaged in inquiry along with other members of a discourse community, teachers will not learn it by listening to hortatory speeches such as this or by being told what pedagogical theory they must apply. They must also function as a discourse community, actively engaging in debate about methodology and pedagogy with their peers and with us, asserting what they know from their experience and allowing those assertions to be tested according to the adequacy of the reasons they are able to create in their defense.

In a situation, such as ours, where many ideas about the teaching of writing are available, many of which are ideologically and methodologically incompatible and all of which have strenuous advocates demanding assent, teachers can easily think it necessary to take sides and to ally themselves with one or another of the prevailing ideologies. I would hope that such an uncritical demand of teachers could be exchanged for one in which they themselves become part of the debate, by being advocates and by being critical audience, so that the issues are kept alive and the investment in knowing how to teach is vital and continuous. But the cost of this enterprise, as I have suggested, is to give up the idea that all the good reasons will be found on one side and that that side represents the truth about teaching writing. As Robert Floden and Christopher Clark (1988) have put it, advocating increased opportunities for professional dialogue among teachers: "Talking can remind teachers that uncertainty is an essential, important part of teaching, not merely a worry and a trouble" (p. 519).

Teachers Must Know How to Live With Ambiguity

Our knowledge of this art--of teaching as well as writing--is not of the sort that enables convictions of the light switch variety: either true or not true. What we know about teaching writing is subject to the tentative agreements that are forged in controversy and communal discussion and it is therefore knowledge that we can only claim to possess *up to a point*. That any method of teaching writing, when it is held to be the true one, will break down, is, I believe, the result of the nature of the enterprise. That is because writing is not

one thing, it is a messy combination of many processes--some fixed, some variable, some known, some unknowable--and any theory or method of teaching writing will be a metaphor--powerful but necessarily limited--of this process. Any way of teaching writing, then, is also a way of not teaching writing.

Our problem is not to decide which particular fact about writing is indispensable. Our knowledge of writing is not of the factual sort. What teachers must know is *how* to get along without such knowledge, how to live with ambiguity, how to muddle through in the face of informed but conflicting viewpoints. Responsible muddling through, if you will accept the possible contradiction in terms, is a matter of working out ways of teaching for oneself, in the thick of the debate about many such ways, knowing that one is responsible to apply the best reasons one can, and that those reasons will always be subject to being tested against the best reasons of others--just as students who learn to write responsibly must also do.

In order for teachers to do this, they must be part of an active community of inquirers, one in which disagreement is tolerated, ideas are listened to, and critical judgment is practiced. The necessary conditions for such a community to thrive are few: Teachers must have access to the debates; they must know the issues that various advocates are addressing. In addition to access to controversies, they must have a forum for discussing them, a collegial setting in which they enter the dialogue by becoming active advocates and critical audience. As teachers are given the resources and are enfranchised to carry on this inquiry among themselves, and if different voices are seriously credited in the process, the outcome can only be that the reasons will get better and that the knowledge of the community of teachers will become more adequate to their own situations. In the end, it is teachers who should be telling each other, not us telling them, what teachers need to know about writing.

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